

OPTICS AND PSYCHOPHYSICS IN A CLINICAL SETTING:
SUCCESS OF A SCREENING BATTERY FOR
ASSESSING VISUAL FUNCTIONING IN HUMAN INFANTS

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**Optics and Psychophysics in a Clinical Setting: Success of a Screening Battery for
Assessing Visual Functioning in Human Infants**

by

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Abstract

Compared to preschool screening, infant vision screening has typically been regarded as much less feasible as infants require more expensive equipment, highly trained personnel, and/or much longer screening times for individual patients. However, early infancy to 3 years marks a critical period of plasticity during which time synaptic connections within the brain are capable of rearranging based on experience. This critical period extends for a variable period of time, but the extent of the plasticity diminishes with age, thus, responsiveness to treatment lessens with age and the depth of impairment is influenced by the duration of the visual abnormality. The evidence for early sensitive, or critical periods, suggests that the best opportunity for prevention and treatment can be expected if screening takes place as early in life as possible.

The primary objective of the present study was to develop and assess a suitable vision screening battery for infants, namely those within the initial stages of the period of visual plasticity. Infants and toddlers (N=189) were assessed with a battery of the latest optical and psychological tests. Within a single session, we attempted to measure, for each eye, optical refractive error, visual acuity, contrast sensitivity, and conducted a full ocular alignment/motility examination.

The battery was relatively successful with all age groups. Notably, all children completed at least one test, 95% completed 2 tests and nearly half (48%) completed 4 tests. Furthermore, the average completion time of the test battery for all age groups was 12.8 minutes with a range across age groups of 9.2 to 13.8 minutes. Thus, the present

study was successful in demonstrating that children between the ages of 6-months and 3 years can be tested on several aspects of visual functioning in a fairly effective and efficient manner using a relatively comprehensive battery of tests. The promising results of the present study highlight the potential to screen children at a much younger age than is currently standard and represents an important step in the assessment and further development of childhood screening programs.

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Introduction

At birth, the human brain is very immature, with both the initial neurons and synaptic connections requiring continuous refinement during a period of postnatal neural plasticity. In fact, during both pre- and post-natal development, many more neurons and synaptic connections are formed than are actually required. The neurons that will ultimately survive and form functional connections with their targets, are determined primarily by the interchange of environmental experience and the heightened plasticity which occurs during the first few years of life.

The visual system, and in particular, the plasticity of the human visual cortex, provides a unique opportunity to investigate the role of the environment on the developing brain. In their now classic experiments, Hubel and Wiesel (1965a,b) were the first to reveal that normal sensory experience shortly after birth is a key component in the physical development of the mammalian visual system. Their initial studies, conducted on newborn cats, investigated the impact of monocular and binocular deprivation on the structure and function of the visual system. Hubel and Wiesel discovered significant morphological and structural changes within the visual pathway of monocular deprived cats, notably that cells in the lateral geniculate nucleus (LGN) responsible for receiving input from the deprived or patched eye, were significantly smaller than cells associated with the non-deprived eye. Thus, the temporary closure of the kitten's lid causes neurons in the visual cortex to become unresponsive to the deprived eye. Additionally, they found that the cortical and functional abnormalities from monocular deprivation were much greater than those produced by binocular deprivation.

Based on these findings, Hubel and Wiesel proposed a developmental mechanism to explain the dramatic changes in cortical function and structure following abnormal sensory experience early in life. They argued that the abnormalities in cortical structure brought on by monocular lid closure reflect the lack of competitive interactions between the two eyes. During normal visual experience, activation of cortical neurons by binocular visual activity leads to a strengthening of the neural connections designed for both eyes. Each eye sends input to a distinct population of cells in the LGN which in turn project to separate and alternating bands of cells in the visual cortex. This segregation forms the basis for the *ocular dominance columns*, i.e., an alternating system of cellular columns arranged in a systematic manner in the primary visual cortex, each of which is devoted primarily to either the left or the right eye. At birth, ocular dominance columns are present but only in their most rudimentary form. With normal binocular visual experience, these columns form bands of equal size and proportion for each eye. In the case of early monocular deprivation however, the active eye's input will be stronger, serving to strengthen the connection, whereas the deprived eye's connection will be weakened. The LGN axons associated with the deprived eye are therefore at a competitive disadvantage and in turn, retract. Conversely, the axon terminals associated with the non-deprived eye continue to connect to cortical cells and may in fact innervate cells occupied previously by geniculate neurons designated originally for the deprived eye. As a result, the columns devoted to the deprived eye become narrow compared to those of the non-deprived eye. Consequently, monocular deprivation alters the architecture of these columns and, therefore, the structure of the visual cortex itself.

However, Hubel and Wiesel discovered that in adult cats, monocular deprivation did not produce comparable cortical effects. From this, Hubel and Wiesel developed the notion of a "critical period" for mammalian vision (Hubel & Wiesel, 1970). The critical period is defined as a time during development when normal environmental input is necessary for a healthy outcome, more specifically, a period during which neurons become differentiated for a specific purpose. During this time, the organism's environmental inputs are the determining factors which strengthen and weaken cortical connections (Hubel & Wiesel, 1970; Wiesel, 1982; Daw, 1994). This activity-dependant process serves to fine-tune the initial, imprecise, genetically-driven growth. If stimulus deprivation occurs during the critical period, visual development will be impaired (Vaegan & Taylor, 1979; Daw, 1995). Therefore, and perhaps most importantly for young human children who experience some form of visual deprivation, this critical period also represents the time during which any treatment is most likely to result in substantial recovery (Ham, Claramunt & Diaz, 1985; Neumann, Friedman & Abel-Peleg, 1987; Stewart, Moseley, Stephens, & Fielder, 2004)

Critical Periods in Human Visual Development

Since the initial experimental work conducted in animals by Hubel and Wiesel, investigation into the nature of plasticity underlying the development of the human visual system has advanced considerably. Recent research has shown that similar critical periods, first identified in kittens, do exist in human visual development (Fiorentini, 1984; Daw, 1994). Clinical studies investigating the impact of visual deprivation on the developing human visual system have evaluated the visual outcome of those affected

with early pediatric visual anomalies, such as strabismus (a misalignment of one eye), anisometropia (unequal refractive error between the two eyes), and congenital cataracts (large opacities on the lens or cornea of the eye). In infants and young children suffering from these conditions, the disruption in normal visual experience during the critical period of plasticity results in degradation of visual input to the central nervous system and marked reductions in visual functioning, especially that in the deprived eye. Many studies have investigated the role of competitive interactions between the eyes by comparing the visual development of visually normal children to that of children who have been deprived of visual experience at some point during early childhood. These studies have shown that, similar to the results found in the cats of Hubel and Wiesel's experiments, children who experienced early unilateral deprivation demonstrated adverse effects from the uneven competition for cortical connections, with notable deficits in monocular contrast sensitivity and visual acuity (Ellemberg, Lewis, Maurer & Brent, 2000; Lewis, Maurer, & Brent, 1995; Lundvall & Kugelberg, 2002). These findings suggest that experience-dependant competitive interactions demonstrated in animal models are also an integral part of the development of the human visual system.

It is generally accepted that the critical period for human vision spans the 4th to about the 36th month of age (Billson, Fitzgerald, & Provis, 1985; Cheng, Hiles, Biglan, & Pettapiece, 1991). Recent behavioral and physiological studies conducted with animal models, however, have revealed that there may actually be different periods of plasticity for different portions of the visual pathway (Harwerth, Smith, Duncan, Crawford & von Noorden, 1986; Daw, Fox, Sato & Czepita, 1992; Bowering, Maurer, Lewis & Brent,

1993). In humans, similar results show that the age of onset of the deprivation influences the type of deficit that the child experienced (as reviewed in Lewis & Maurer, 2005). This suggests that critical periods may vary in both duration and onset for different brain regions and cortical layers and, consequently, for different visual functions (Daw et. al., 1992; Daw, 1995). Additionally, critical periods do not appear to follow a strict time-course, but instead appear to reduce slowly, reflecting both the progressive reduction in plasticity and the associated consolidation of functional neural cells and synaptic connections. This is reflected in the observation that as childhood progresses, longer periods of deprivation are required to produce neural changes and the associated visual impairment (Lewis & Maurer, 2005).

Although much is now known about the effects of monocular deprivation in animal models and the detrimental visual and neurological effects observed in humans, relatively little is known about the exact time-course of human visual plasticity and the associated critical periods. Such knowledge has enormous clinical implications, as critical periods not only represent a time during which the developing visual system is susceptible to abnormal visual experience, but also represent a time of enhanced responsiveness to treatment. Gaining insight into the time-course of development, and in turn, the critical periods for various aspects of vision, would be invaluable for determining the proper course of detection, treatment and prognosis (Simons, 2005). Consequently, determining the exact time frame and duration of critical periods would maximize recovery after treatment for early vision anomalies. If impairments are identified and treated during the critical period, recovery of function can be substantial

(Birch, Stager, & Wright, 1986; Ham et al., 1985; Cheng, Hiles, Bilgan & Pettapiece, 1991; Drummond, Scott, & Keech, 1989; Lewis, Maurer, & Brent 1989; Maurer, Lewis, Brent, & Levin, 1999; Stewart et al., 2004). In many cases, early detection of visual abnormalities (i.e., anisometropia, strabismus, or cataracts) can lead to complete recovery of visual functioning if intervention is implemented before anatomical changes become permanent (Birch et al., 1986; Birch, Swanson, Stager, Woody, Everett, 1993; Cheng et al., 1991; Drummond et. al., 1989; Maurer et al., 1999).

However, if visual abnormalities are left undetected they may lead to permanent visual impairment, most notably in the emergence of *amblyopia*. Amblyopia is defined as reduced visual acuity (usually in one eye) that occurs in the absence of any obvious structural abnormalities and is believed to result from abnormal visual experience early in life (Cuiffreda, Levi, & Selenow, 1991; von Noorden, 1990). Amblyopia accounts for more cases of *preventable* visual impairment than all other causes combined, with a prevalence rate in Canada of about 4% (Robinson, Bobier, & Martin, 2000; Ross, Murray, & Stead, 1977).

There are several known sources of infantile deprivation that lead to the development of amblyopia (i.e., the predisposing amblyogenic conditions). First, *strabismic amblyopia* is the most common form and is a result of the misalignment of the visual axes between the two eyes, with the deviating eye turning either inward (esotropia) or outward (exotropia) (Ciuffreda, et al., 1991). Second, *anisometropic amblyopia* is caused by a significant difference in refractive error between the two eyes (usually defined as a difference of 1.5 dioptres or greater). Third, *image degradation amblyopia* is

due to an optical obstruction such as a cataract in the lens, a corneal opacity, ptosis, and/or a vitreal hemorrhage in one eye. Finally, *ametropic amblyopia* occurs in both eyes and results from substantial uncorrected binocular refractive error (i.e. myopia, hyperopia and/or astigmatism) (Werner & Scott, 1985; Schoenleber & Crouch, 1987; Edelman & Borchert, 1997). Amblyopia typically manifests as a unilateral condition and all forms of amblyopia develop as a direct consequence of a disruption in visual input during the critical period in early visual development. During development, because there is unequal stimulation of the retina, the central nervous system adapts to receive the more detailed image from the non-deprived eye and progressively suppresses the input from the deprived eye (von Noorden, 1990). The result is an imbalance of visual input from the two eyes leading to an unequal ocular dominance distribution and a reduction in binocular cortical cells. The loss of binocular cells contributes to the reduction of visual functioning in the affected eye.

Though traditionally defined as a visual acuity deficit, it is now generally accepted that amblyopia impacts several visual functions (Wali, Leguire, Rogers, & Bremer, 1991; Kiorpes, 1992), namely contrast sensitivity, depth perception and binocularity, all of which have distinct time-courses of development and, in turn, distinct periods of heightened plasticity (Daw et al., 1992). Therefore, identifying the exact onset and duration of plasticity for different visual functions is fundamental to the diagnosis and treatment of amblyopia.

Despite its potentially devastating effects, amblyopia is remarkably responsive to timely therapeutic intervention and treatment. With early detection, many cases of

amblyopia are completely reversible (Wu & Hunter, 2006; Cheng et al., 1991; Drummond et al., 1989; Maurer et al., 1999). Recovery of function depends significantly on the type of amblyopia, depth of the impairment, age of onset, duration of impairment, and treatment compliance (Flynn, Woodruff, Thompson, Hiscox, Feuer, Schiffmann, Corona, & Smith, 1999; Hiscox, Strong, Thompson, Minshull, & Woodruff, 1992; Lennerstrand & Rydberg, 1996; Simon & Kaw, 2001; Elder, 1994; Lithander & Sjostrand, 1991). Therefore, from a clinical perspective, it is believed that treatment will be maximally beneficial if administered during a time in which the visual system is still relatively impressionable (Ciuffreda et al., 1991; Mills, 1999; Williams, Northstone, Harrad, Sparrow, & Harvey, 2002). The general consensus has been that the first 24 to 36 months of life represent a period of significant plasticity, and thus, the critical period for human visual development (Billson et al., 1985; Cheng et al., 1991). However, in light of new research, both the maturational time frame of human visual development and the length of the corresponding plasticity have been questioned. Research has suggested that the neuronal volume within the visual cortex may continue to increase well into the 6th year of life and that structural development within the visual cortex may be more prolonged than previously thought and may extend into adulthood (Giedd, Blumenthal, Jeffries, Castellanos, Zijdenbos, Paus, Evans, & Rapoport, 1999; Sowell, Thompson, Holmes, Jernigan, & Toga, 1999). Additionally, although visual functions such as visual acuity, stereopsis, and contrast sensitivity emerge and undergo substantial improvements during the first 6 months of life, they do not reach adult-like levels until sometime between 5 to 9 years (Dobson & Teller, 1978; Gwiazda, Brill, Mohindra, & Held, 1980;

Adams & Courage, 1993; Adams & Courage, 1996; Elleberg, Lewis, Liu & Maurer, 1999). Similarly, other research has found that the critical period for recovery from amblyopia and its associated risk factors may extend beyond the critical period of development, as treatment may be efficacious throughout adolescence and into adulthood (Daw, 1995; El Mallah, Chakravarthy & Hart, 2000; Karatza, Shields & Shields, 2004). However, interest still persists in establishing early screening programs that are both cost and clinically effective, as results from studies of adult amblyopes are inconclusive, and it has yet to be determined if such later visual improvements are permanent. In addition to the incomplete evidence from adult studies, recent research also shows strong evidence for a heightened risk of visual impairment in the better eye of amblyopes (Simons, 2005). Furthermore, although there may be hope for visual recovery into adulthood, amblyopes experience significant detrimental psychosocial effects during childhood that can only be avoided with early intervention. It remains therefore, that complete prevention of amblyopia through early detection of amblyogenic factors is still the most effective clinical strategy.

Implications for Vision Screening

Given the now very clear evidence which shows that recovery is enhanced with early detection, combined with the recent emergence of new pediatric testing technologies, there is growing interest in developing early vision screening programs. The general consensus remains that vision screening should begin by three years of age. Currently, most screening programs aimed at detecting amblyopia and the associated risk factors, still target children between 3 and 6 years (Anker, Atkinson, Braddick, Ehrlich,

Hatley, Nardini & Wade, 2003). Although this age range does fall within the upper end of the critical period of visual development, researchers and physicians agree that if a child is not receiving treatment by the age of 5, they are unlikely to benefit maximally from any treatment. Additionally, there remains much discrepancy about which visual functions should be assessed (Anker et al., 2003). Typically, vision screening during the first 2 years of life is limited to a very basic structural examination. However, complex visual anomalies that may be detrimental in the long run may appear initially quite subtle (e.g. anisometropia, ocular suppression, and/or a slight or intermittent strabismus), and therefore, will remain undetected unless a more comprehensive early visual screening procedure is conducted. Likewise, it is firmly believed that maximally efficacious treatment is achieved when visual abnormalities are detected under the age of 2 or 3 years, with treatment efficacy, duration and compliance being most predictive of treatment success (Simons, 2005).

Although, traditional vision screening has been performed with objective tests in literate children (e.g., Snellen letters) there are now new tests and technologies that can be used to assess visual functioning in younger pre-verbal children. There is still uncertainty about whether these techniques can be administered in a clinical setting and/or whether they are cost effective. Nonetheless, the early results are encouraging, as recent research shows that multiple screenings conducted during the first 24 to 36 months reduces the prevalence of amblyopia (Simons, 2005). Several countries, notably Sweden and Israel, have implemented screening programs that begin before the age of 2. In both countries the severity and prevalence of amblyopia have been reduced significantly. In

Sweden the prevalence of deep amblyopia has been considerably reduced from 2% to 0.2% with the implementation of an early screening program for children from birth to 10 years of age (Kvarnstrom, Jakobsson & Lennerstrand, 2001). Furthermore, the Avon longitudinal study conducted in the United Kingdom revealed that screening conducted six times between the ages of 8 and 37 months decreases the prevalence of amblyopia at 7.5 years to 0.6% compared to 1.8% for children screened one time at 37 months (Williams et al., 2002).

Further support for early vision screening comes from several studies which highlight the predictive nature of visual functioning during infancy. For example, the Cambridge Infant Vision Screening Program used videorefraction to screen 8- and 9-month-old infants. Untreated infants with significant hyperopia were more likely to become strabismic and demonstrate poor acuity at 4 years of age compared to infants without high refractive error (Atkinson, Anker, Nardini, Braddick, Hughes, Rae, Wattam-Bell, & Atkinson, 2002; Anker et al., 2003). In a follow up study, Atkinson and colleagues revealed that infants with high hyperopia identified at 9 months of age, showed deficits compared to refractively normal children on various visuomotor and visuocognitive tasks at 2, 3.5 and 5.5 years of age (Atkinson, Nardini, Anker, Braddick, Hughes, & Rae, 2005). This suggests that persistent impairment may be a result of uncorrected refractive errors that first appear during infancy and also suggests a possible relationship between early vision screening results and the broader aspects of visual and cognitive development.

Although there is mounting evidence to suggest that early infant vision screening is effective in reducing the prevalence of amblyopia, the intensive experimental screening programs mentioned above which involve multiple screenings throughout the first 24 to 36 months are not economically feasible for most healthcare settings. This again highlights the importance of pinpointing critical periods of visual plasticity during which detection and treatment can yield profound improvements in eye and cortical functioning. The Canadian Pediatric Society along with the American Academy of Pediatrics both suggest that vision screening should begin at birth, with regular assessments of visual functioning continuing throughout childhood (Wu & Hunter, 2006; Community Pediatrics Committee, 1998). However, the greatest discrepancies between the major vision and pediatric organizations centre on *which* aspects of vision should be assessed, and *when* such assessment should begin. The five critical components of vision most often assessed during a typical vision screening procedure are visual acuity, ocular alignment, stereoacuity, refractive error, and contrast sensitivity. However, the lack of understanding regarding both the development of these functions and the associated critical periods likely contributes to the lack of consensus on the appropriate tools that need to be used to assess these functions throughout childhood, as well as the appropriate timing of initial assessment. Gaining a better understanding of the developmental time course for each of these visual functions may be the key to determining the most appropriate time for initial assessment. The following section provides a brief overview of what is currently known about the development of the primary visual pathway and visual functions during the first few years of life.

Early Visual Development & Current Methods of Early Vision Assessment

During the first 6 months of life the visual system undergoes significant anatomical and functional development. At birth, the retina, LGN and visual cortex are functionally immature. The primary visual pathway becomes functional around 2 to 3 months of age, with the central visual pathway continuing to mature into the preschool years, reaching maturity at around age 5. The primary visual cortex is believed to reach adult volume very early in development, by approximately the 4th post-natal month. However, synaptic density becomes adult-like much later, by about age 4. Maturation of the retina, myelination of the optic tracts and increased synaptic density of the visual cortex throughout the first 6 months of life reflect the significant improvements seen in spatial vision, contrast sensitivity, color vision, and binocularity shown by infants during this time (Mills, 1999; Dobson & Teller, 1978; Birch, Gwiazda, & Held, 1982; Birch, Gwiazda, Bauer, Naegell, & Held, 1983; Braddick, Atkinson, Julesz, Kropfl, Bodes-Wollner, & Raab, 1980; Atkinson, French, & Braddick, 1981; Ellemberg et al., 1999; Courage & Adams, 1990; Adams, Mercer & Courage, 2004; Oliveira, Costa, de Souza & Ventura, 2004).

Spatial (pattern) vision is considered the most critical of all human visual functions, which again highlights the need to protect against early spatial abnormalities and thus prevent amblyopia. Typically, spatial vision is assessed with tests of visual acuity. Visual acuity of literate children and adults is assessed most easily with a measure of recognition acuity (e.g., Snellen Letters) which refers to the smallest visual target (optotype) that is recognized. In pre-literate patients, picture optotypes such as a

simple geometric shape (e.g., Lea Test) are used instead of letters. Though picture optotype tests of recognition acuity are often useful in children as young as 2 or 3, they can not be used for younger non-verbal patients (i.e., infants) or the cognitively delayed. Instead, visual acuity in these populations is measured with tests of resolution acuity in which the subject need only detect the presence of a pattern. Tests of resolution acuity include the Teller Acuity Cards (TAC) and the Wright Cards (McDonald, Dobson, Sebris, Baitch, Verner, & Teller, 1985; Raina, 1998). Both the Teller and Wright Cards consist of a series of rectangular cards with a black and white patterned stimulus on one end and an unpatterned stimulus of equal average luminance on the opposite end. The spatial frequency of the striped grating of the TACs or the checkerboard pattern of the Wright Cards varies from low spatial frequency (thick stripes/checks) to high spatial frequencies (thinner stripes/checks). To administer these tests, the examiner follows the forced-choice preferential looking method (FPL), which is based on the concept that the novel or patterned stimuli will capture the subject's attention more readily than will a blank stimulus. It is assumed that if the infant can resolve the elements within a particular grating, he or she will show a visual preference for the patterned side of the card. The highest spatial frequency (e.g. thinnest stripe size) that evokes a reliable visual preference is taken as the estimate of visual acuity.

The Teller Acuity Cards have been adopted widely as a clinical assessment tool for infants and have become a standard component within the ophthalmologic examination of infants and young children. The TAC test provides an accurate estimate of visual acuity and can be administered quickly and conveniently in a pediatric clinical

setting. The TAC test has demonstrated consistent high inter- and intra-observer reliabilities, (McDonald et al., 1985; Hertz & Rosenberg, 1988; Harvey, Dobson, Tung, Quinn & Hardy, 1999), and relatively high predictive value, as well as high specificity for identifying children with normal vision (Mash & Dobson, 1998; Hall, Courage & Adams, 2000). However, the ability of the TAC test to identify abnormal vision is much less powerful. Researchers agree that the results from this test should not form the sole basis of clinical decision making and should be paired with other tests to obtain a broader perspective on a patient's visual status. The long-term reliability of the TAC test is still in question with several studies showing that initial measures taken during infancy are not predictive of later visual functioning (Hall et al., 2000).

The shortcomings of the TAC test have highlighted the need for a more comprehensive index of spatial vision. Tests of visual acuity measure sensitivity to objects of varying size that are at fixed high contrast levels, but such stimuli are not representative of real-world objects which vary in both size and in contrast (Drover, Earle, Courage, & Adams, 2002). A more comprehensive estimate of visual functioning is to measure contrast sensitivity (CS) which assesses the ability to detect, simultaneously, objects of different size and contrast (Campbell & Robson, 1968). Specifically, tests of CS estimate the minimum amount of contrast required to detect sine wave gratings at different spatial frequencies (i.e., target size). In recent years, CS has emerged as the most complete single measure of human spatial vision as it provides an index of a patient's maximal spatial resolution (visual acuity) as well as the minimum contrast threshold required to detect targets of all possible sizes (Drover et al., 2002).

Additionally, the reciprocal of each contrast threshold (minimum amount of contrast required) can be plotted to form a subject's contrast sensitivity function (CSF). The shape of the CSF (typically an inverted-U) is useful clinically, as deviations within specific segments (i.e., at specific spatial frequencies) give an indication of the type of underlying ocular or neural disease. This is particularly useful in the case of amblyopia. Measures of CS provide a more complete picture of the visual losses experienced by patients, and different types of amblyopia have specific effects on different segments of the CSF (Hess & Holliday, 1992; Kushner, 1998; Lennie & van Hemel, 2002). As a result, clinicians and researchers have shown great interest in developing a means of assessing CS early in life.

Based on the TAC procedure, the sine-wave based contrast sensitivity card procedure has shown promise as a time-efficient method that can be used to assess contrast sensitivity from early infancy until maturity (Adams, Mercer, & Courage, 1992; Adams & Courage, 2002; Drover et al., 2002). However, the CS card procedure still requires validation as a useful and efficient clinical tool for the assessment of visual functioning in early infancy. In particular, tests of contrast sensitivity have yet to be used in any mass screening program and there are no referral criteria for this test.

Measurement of refractive error is often cited as a critical component of any screening program. Although refractive change can occur throughout life, the most critical development occurs during infancy (Larsen, 1971a,b,c,d; Pennie, Wood, Olson, White, & Charman, 2001). Full-term newborn infants are hyperopic and display moderate levels of astigmatism (Graham & Gray, 1963; Kuo, Sinatra & Donahue, 2003; Patal,

Naturajan & Abreu, 1970). Similar to the development of the visual cortex, the growth of the eye is not simply an increase in scale but instead, different parts of the eye grow at different rates (Pennie et al., 2001; Spooner, 1957). For those who eventually become emmetropes (i.e., have normal optics), these neonatal refractive errors diminish within the first 6 to 8 months (Ingram & Barr, 1979; Gordon & Donzis, 1985; Saunders, 1995). However, proper identification of non-reducing levels of hyperopia, astigmatism (or very rarely, myopia) is critical for ensuring balanced visual input from both eyes, especially during the early years of life when uncorrected refractive error can cause permanent losses in visual acuity and binocularity (Atkinson, Braddick, Nardini & Anker, 2007; Saunders, 1995; Howland & Sayles, 1987). In addition to the negative long-term effects associated with persistent uncorrected refractive error, early optical status also appears to predict later visual and cognitive functioning (Atkinson et al., 1996; Anker et al., 2003; Atkinson et al. 2005).

The traditional technique for measuring refractive error in infants and young children is retinoscopy, which is often conducted with the use of cycloplegic drops to prevent accommodation. Cycloplegic retinoscopy is considered the gold standard for obtaining refractive error estimates, although it requires a high degree of clinical expertise and is sometimes very time-consuming (Kohler & Stigmar, 1973; Nordlow & Joachimsson, 1962). Other methods for assessing refractive status in infants and young children such as near retinoscopy, videorefraction, and photorefraction have shown accurate and comparable results to those obtained during gold standard examination. However, these methods are time-consuming, require a fair level of expertise and are

generally not conducive to the screening setting (Adams, Dalton, Murphy, Hall & Courage, 2002). In response to the need for a more practical refractive screening device, several companies have developed hand-held autorefractors that are capable of measuring refractive error in a time-efficient manner. Autorefraction is still a relatively new technology, and pediatric and vision associations have yet to make recommendations for referral criteria for different ages. Research has shown that it is a reliable measure for determining refractive status in infants and young children, producing similar results to those obtained with gold standard cycloplegic retinoscopy (Chan & Edwards, 1993; Adams et al., 2002). However, some researchers remain skeptical about its testability and validity with very young children (Kemper, Keating, Jackson & Levin, 2005).

Significant changes in refractive status during the early months of life are accompanied by the onset of binocularity in the human visual cortex which occurs sometime between 10 and 16 weeks of age (Braddick & Atkinson, 1983; Birch & Held, 1983). Binocularity refers to the ability to perceive images from both eyes simultaneously. Closely related to this aspect of vision is stereopsis which refers to the ability to determine depth. Both require fairly precise eye alignment and properly synchronized eye movements to ensure normal development (Mills, 1999). During the first 6 weeks of life, eye movements are immature and most infants' eyes are misaligned. Typically, eye alignment becomes stable around the 3rd month, and abnormalities are then usually detectable after that age (Mills, 1999). Strabismus, or misalignment of the eyes, is the most common cause of amblyopia and therefore of importance in early eye/visual evaluation. Ocular alignment is easily assessed from early infancy onward by measuring

the Hirschberg corneal reflex or by administering the cover test. Ocular motility which is directly related to alignment, is examined by close examination of eye movements and by inspection of converging/diverging movements of the eyes.

Tests of stereopsis are also often included in vision screening programs in order to measure the more precise aspects of binocular functioning (Simons, 1996). Stereoacuity is an index of an individual's stereopsis and is measured with targets that vary in perceived retinal disparity (measured in seconds of arc). There are numerous tests of stereoacuity (e.g., The Random Dot E Stereo Test, The Randot Preschool Stereoacuity Test and The Wirt Fly Test) that are utilized in clinical settings, with some designed for children as young as 1 year.

However, despite the emergence of many new technologies, the initial age at which visual functioning should be assessed remains to be determined. Additionally, there remains no clear consensus on the tests that need to be included within an early vision screening program. Therefore, there is a need for further research into the testability of young pediatric populations, as well as the efficiency of the newly developed visual assessment tools within a clinical or screening setting.

The Present Study

The primary objective of the present thesis is to attempt to develop and assess a suitable vision screening battery for infants, namely those within the initial stages of the period of visual plasticity (6-12 months). Currently our laboratory conducts a large-scale, population based program to assess preschool children between the ages of 2 and 5. Using a procedure modified for a younger population, we hope to show that young

infants can be screened successfully in a timely, non-invasive, practical manner.

Compared to preschool screening, infant vision screening has typically been regarded as much less feasible (or perhaps even impossible) as infants require more expensive equipment, highly trained personnel, and/or much longer screening times for individual patients. However, promising new tests such as the CS Cards and the Welch Allyn SureSight autorefractor along with traditional techniques such as the TAC, may now permit estimations of a young child's visual capacities within a few minutes. We hope to demonstrate that by using less invasive, easily administered behavioral techniques, an effective and reliable program can be developed for infants.

To our knowledge, only a few studies have been conducted which evaluated the effectiveness and efficacy of infant vision screening and currently there are very few infant screening programs implemented worldwide. Those which do, have focused solely on measures of refraction (i.e., videorefraction, photorefraction, and/or retinoscopy). The present research will be the first to evaluate the feasibility of screening infants with a broad range of tests which assess all of the important components of visual functioning. In doing so, we will estimate the prevalence of visual abnormalities among this very young and under-studied population in order to provide some data on early amblyogenic factors. By including this younger population in the screening program we also hope to gain a better understanding of the rapid visual development that occurs during the critical period of neural and visual plasticity. Moreover, by including very specific age groups within our analysis, the present research will provide more precise developmental data than is currently available in the literature. Finally, including infants in a screening

program marks a critical first step in determining whether early vision screening during infancy is feasible and whether measures taken during infancy can be predictors of later visual functioning and visual pathology.

Method

Participants

189 toddlers and infants were tested between September 2005 and November 2007. The present study comprised 4 age groups of children: 6 month-olds (5 to 7 months), 1-year-olds (11 to 13 months), 2-year-olds (22 to 29 months), and 3-year-olds (36 to 37 months). Figure 1 shows the age distribution of all children in the study. Children ranged in age from 5 months to 37 months of age with a mean age of 23.9 months ($SD = 11.3$ months). All of the 189 children were included in the analyses.

To recruit 2- and 3-year-olds, consent forms were sent to daycare centers throughout the St. John's, Newfoundland metropolitan area (Appendix A). All children whose parents/guardians provided consent, were then tested within the child's daycare, by either the author, a trained research assistant, or a Ph.D. student, all of whom received the same training. Infants between the ages of 5 and 13 months-old were recruited by providing information to mothers during maternity stays at the St. John's Region Health Science Center. Parents of infants were later sent information regarding the study, and then followed up by phone. All of those wishing to participate were assessed at the Infant and Child Vision Research Center, Memorial University, St John's campus. Not every child completed the entire battery of tests ($N = 54$) due to cognitive or attentional

limitations. For 2- and 3-year-olds tested within their daycare setting those who did not complete the entire set of tests on the first attempt, were re-tested at a later date.

However, 6- and 12-month-old infants were tested only once, and every attempt was made to complete the test battery during that visit.

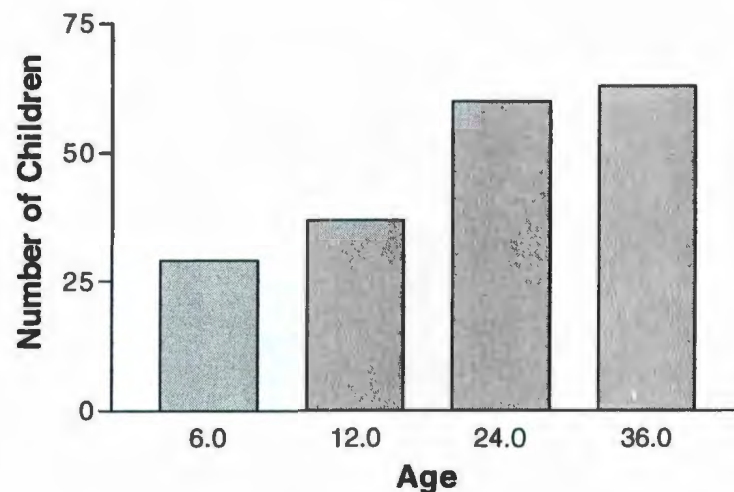


Figure 1. Age distribution of children in the present study.

Materials and Procedure

Tests used to measure each child's functional vision were selected based on the child's age. Therefore, 6- and 12 month-olds were evaluated with tests slightly different from those used for 2- and 3-year-olds and these are outlined in detail below.

Visual Acuity

Infant's visual acuity was assessed with the Teller Acuity Cards (TAC). The TAC consists of 16, 26 X 56 cm rectangular cards, 15 of which have vertical black and white, square wave gratings on one side (i.e., the left or right hand side) of the card (see Figure 2). Between cards, the spatial frequency of the gratings ranges in half-octave steps from

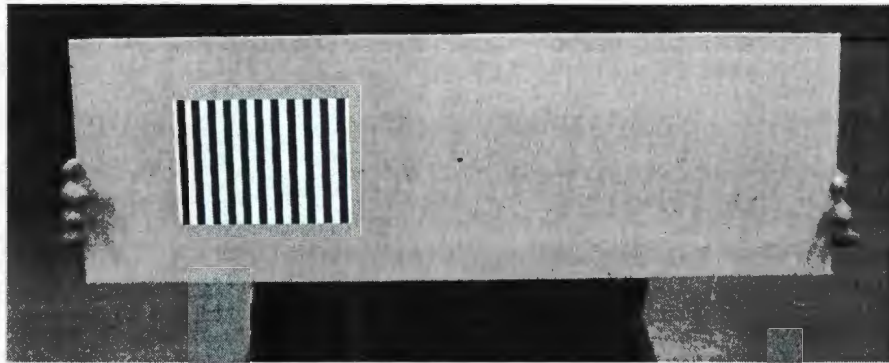


Figure 2. Photograph of a Teller Acuity Card (0.43 cy/deg, Snellen Equivalent = 20/1000).

0.3 (20/1200) to 38 (20/10) cy/deg when viewed from 55 cm. The additional 16th card, the “control card”, was blank. All infants were placed on the parent’s lap 55cm from an observer who administered the tests to all infants. Visual acuity was assessed monocularly by having children wear glasses which contained a patch that covered either the left or right eye. In some instances, the child refused to wear the glasses and visual acuity was therefore assessed binocularly.

The tester first administered the warm-up card containing a grating of a very low spatial frequency (i.e., a 0.1 cy/deg grating that contained very thick stripes and was easily visible). This was followed by the presentation of the blank control card in order to determine the child’s response to an undetectable grating. The tester then presented the child with the first test card, a card of low spatial frequency (0.3 cy/deg). At this point the tester was unaware of the location of the target (i.e., whether the grating was on the left or right side of the card). Each card was presented two or more times in succession, with the position of the target alternated randomly for each trial. After making a decision about the location of the target, the tester then observed the front of the card to confirm the

grating's location. Cards with gratings of increasingly higher spatial frequency were then presented until the tester made a judgment that the child could not resolve a particular target. The finest grating that the child could resolve was taken as the estimate of his/her visual acuity.

Visual acuity of 2- and 3-year-old toddlers was assessed with a variety of tests. The test chosen was based on the child's comprehension of the task and his/her cooperation. The preferred test for screening preschool aged children was the Patti Pics linear optotype test (See Figure 3; Precision Vision, LaSalle, Illinois., U.S.A). This test consists of 8 rows of 5 optotypes (circle, square, apple and house) ranging in size from 20/80 to 20/16. To keep luminance constant, the chart was mounted in a cabinet which illuminated the chart to approximately 170 cd/m^2 . To assess acuity monocularly, children sat 3 m from the chart and wore glasses with either the left or right lens covered with masking tape. As the tester pointed to the symbol on the chart, the child was asked to name the optotype or point to the corresponding shape which was shown on a large card that the child viewed in front of him/her. Like the adult Snellen chart, to successfully complete a single line, the child had to correctly identify 4 of the 5 optotypes. The lowest line at which the child could correctly identify 4 of the 5 optotypes was taken as a measure of visual acuity.

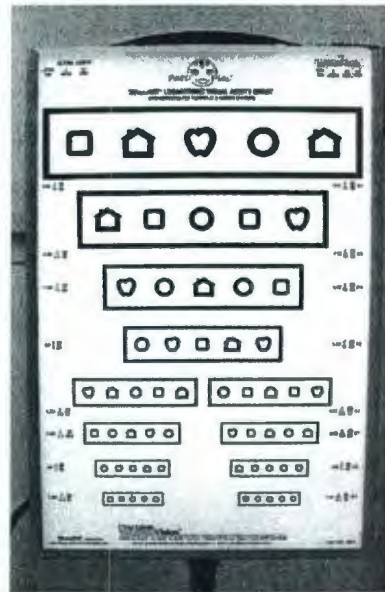


Figure 3. Photograph of the Patti Pics linear optotype test

Toddlers who could not complete the Patti Pics linear optotype chart were tested with the PattiPics two-alternative, forced-choice cards (see Figure 4). This test consists of 30 cards, each with an optotype on the front and back of the card, with optotypes ranging in size from 20/200 to 20/8. Testing was conducted monocularly at a distance of 3m. The child was presented with 2 cards with 2 different optotypes of the same size, beginning with the largest (i.e., 20/200), and was asked to point to the shape instructed by the tester. If the child did not point, then the child's fixation was taken as an indication of whether or not s/he could resolve the optotype. Several combinations of cards were shown to the child at each optotype size, and the child was required to identify successfully at least 4 optotypes. The smallest optotype size the child could identify correctly was taken as an estimate of visual acuity.

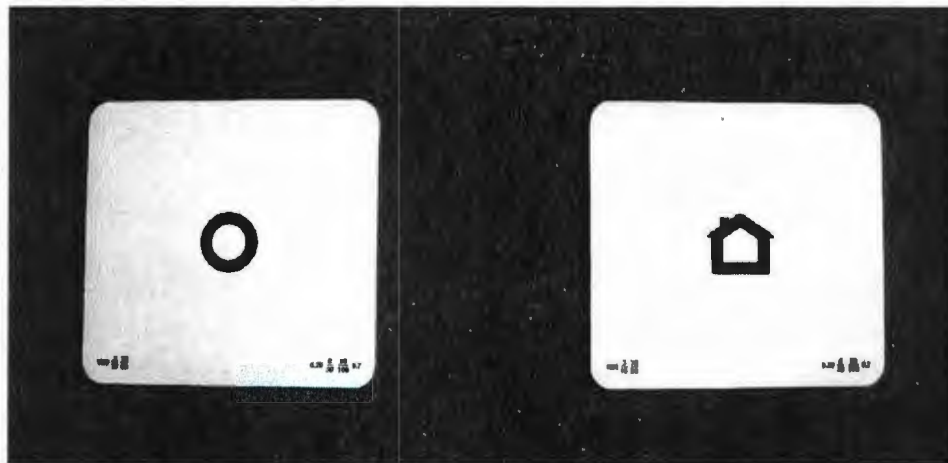


Figure 4. Photograph of the Patti Pics two-alternative-forced-choice isolated symbols test.

Contrast Sensitivity

Contrast sensitivity was assessed in 6-month-olds, 12-month-olds and 2-year-olds with the contrast sensitivity (CS) cards (Drover et al., 2002). The CS cards are 20, 22 x 56 cm rectangular cards, each consisting of 2 circular patches positioned at an equal distance from a 2 mm peephole drilled into the center of the card (see Figure 5). One patch is the “test patch” which is composed of a vertical, sine wave grating of a specific spatial frequency (SF) and contrast. The other patch, the control patch, is located on the other end of the card and consists of a vertical sine wave grating with the same spatial frequency as the test patch, but with 0% contrast (i.e., it appears blank). As Table 1 shows, the 20 CS cards are divided into 5 subgroups based on the spatial frequency of the test patch (0.75, 1.5, 3.0, 6.0, or 12.0 c/deg). Each set contains a high contrast test patch (48 to 57%) which serves as a “warm-up” card and is presented first to capture the child’s

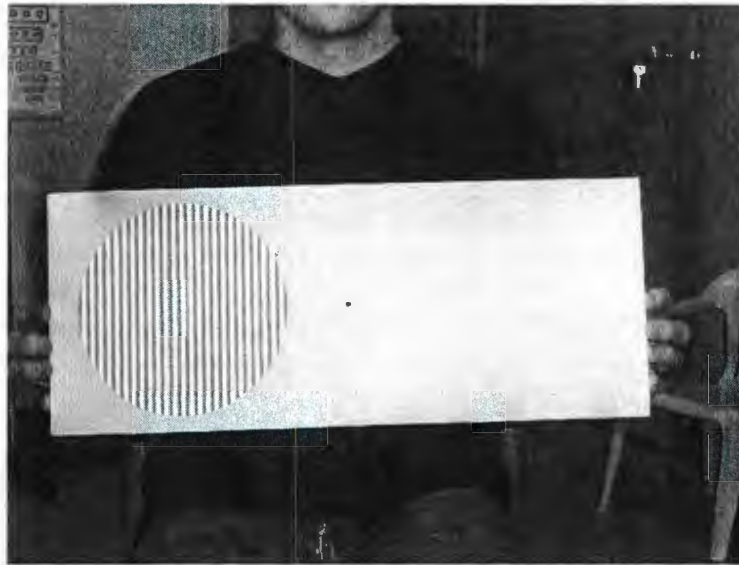


Figure 5. Photograph of a contrast sensitivity card (3.0 cpd, 48% contrast).

Table 1. Contrast values (expressed in percent contrast) and the spatial frequencies of the gratings in each CS card. The values in parentheses below the percent contrast values represent each grating's contrast converted to CS units.

	Card Number in Each Set				
	1	2	3	4	5
Spatial Frequency Set					
0.75	57 (2)	22.7 (4)	6.4 (18)	4.8 (21)	
1.5	48.1 (2)	22.7 (4)	6.4 (18)	4.8 (21)	3.6 (28)
3	48.1 (2)	22.7 (4)	5.9 (17)	2.6 (39)	
6	48.1 (2)	31.7 (3)	8.7 (11)	2.6 (39)	
12	57 (2)	31.7 (3)	22.7 (4)		

attention and to show him/her an example of that SF. Each spatial frequency set also contains lower contrast cards, ranging from 31.7 to 2.6% contrast.

Testing was conducted monocularly at a distance of 60 cm. The general procedure for the CS card is modeled after the modified version of the forced-choice preferential looking method (FPL), used for the Teller Acuity Cards (Adams et al., 1992). To test each SF set, the warm-up, or high contrast test card was administered first. 2- and 3-year-olds were instructed to point to the side of the card with the test patch. For infants, eye and head movements in the direction of the test patch were taken as an indication of whether or not the grating was detectable. Each card was rotated several times and presented usually about 4 to 5 times. If the toddler pointed correctly to the test patch, or if an infant showed a consistent and reliable fixation for the test patch, it was judged that it was detectable. The tester remained blind to the location of the test patch throughout the procedure. Testing continued with each SF set by presenting cards of lower and lower contrast until the test patch was no longer either pointed to or fixated by the child, and presumably was now undetectable. Within each SF set, the lowest contrast grating that was detected reliably by the child was taken as a measure of the contrast threshold for that SF.

The contrast sensitivity of some of the 3-year-olds was assessed with the *CS screening booklet* (Drover, Courage, Dalton & Admas, 2006; see Figure 6). The booklet, a recent replacement for the cards and designed for older children, consists of 168, 21.6 X 27.9 cm gray pages in a 3- ring binder. The test and control patch are located 12 cm from a central 1mm thick white line. As Table 2 shows, the booklet, similar to the CS cards,

consisted of 5 sets of SF (0.75, 1.5, 3.0, 6.0, 12.0 c/deg) with contrast ranging from 53.4% to 0.9% at each

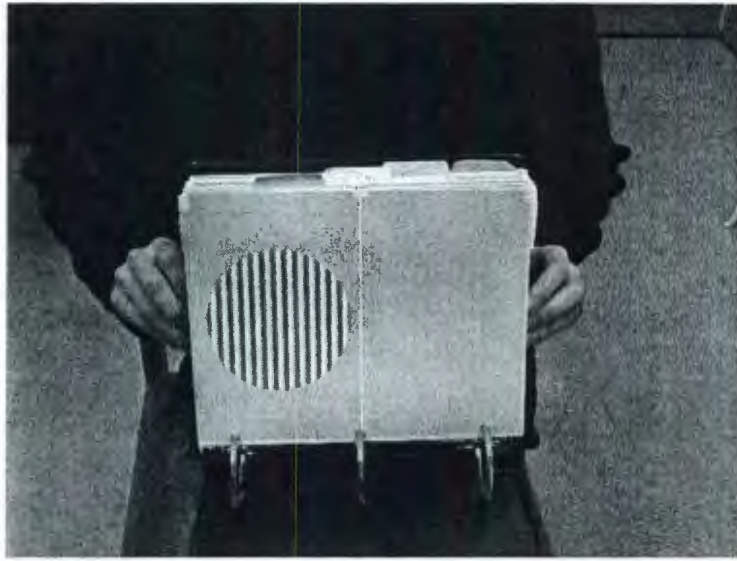


Figure 6. Photograph of a page of the contrast sensitivity booklet (0.75 cpd, 48.7% contrast).

contrast level. Testing of the booklet was conducted monocularly at 40 cm and follows the same general procedure as the CS cards to estimate contrast thresholds at each spatial frequency.

Previous research conducted within our lab demonstrated that testing very young children with the CS cards is rather time-consuming and is often not completed successfully. For this reason, the present study also incorporated the Peek-a-boo Patti Low Contrast Test (Precision Vision, LA Salle, Illinois, USA; See Figure 7) in order to ensure at least one estimate of a child's ability to detect objects of low contrast. This test consists of 4, 21 x 26 cm cards. Three of the cards are test cards, each of which contains a schematic child's face, on the back or front which is composed of a single contrast (either

100%, 25%, 10%, 5%, 2.5% or 1.25%). The highest contrast face (100%) was used as a warm-up card, and the fourth card was blank. The tests cards were presented to each

Table 2. Contrast values (expressed in percent contrast) and the spatial frequencies of the gratings in each CS card. The values in parentheses below the percent contrast values represent each grating's contrast converted to CS units.

	Card Number									
	1	2	3	4	5	6	7	8	9	10
Spatial Frequency Set										
0.75	48.7 (2)	21.8 (5)	11.5 (9)	7.9 (12)	5 (20)	3.6 (28)	2.7 (37)	1.4 (71)		
1.5	47.6 (2)	21.8 (5)	10.4 (10)	7.3 (14)	4.9 (20)	3.7 (27)	2.4 (42)	1.2 (83)	0.9 (111)	
3	48.4 (2)	21.8 (5)	10.7 (9)	7.4 (14)	5.3 (19)	3.8 (26)	2.5 (40)	1.9 (53)	1.2 (83)	0.9 (111)
6	54 (2)	29.8 (3)	15.7 (6)	8.3 (12)	4.8 (21)	3.3 (30)	2.5 (40)	1.4 (71)		
12	53.4 (2)	30.3 (3)	20.3 (5)	10.4 (10)	4.8 (21)	2.5 (40)	1.4 (71)			

child 4 to 5 times, along with the blank card, with the location of the target alternated between trials. Testing was conducted monocularly at a distance of 60 cm. Toddlers were asked to point to the location of the target, and for infants, eye fixation and head movements were taken as an indication of detection. Testing initiated with the card of the highest contrast and continued with cards of progressively lower contrast. If the child correctly identified the location of the target at least 4 times out of 5, it was judged that that contrast level was detectable. The tester remained continually blind to the location of

the target until testing was complete. The lowest contrast at which the child could correctly identify the target was taken as an estimate of contrast threshold.

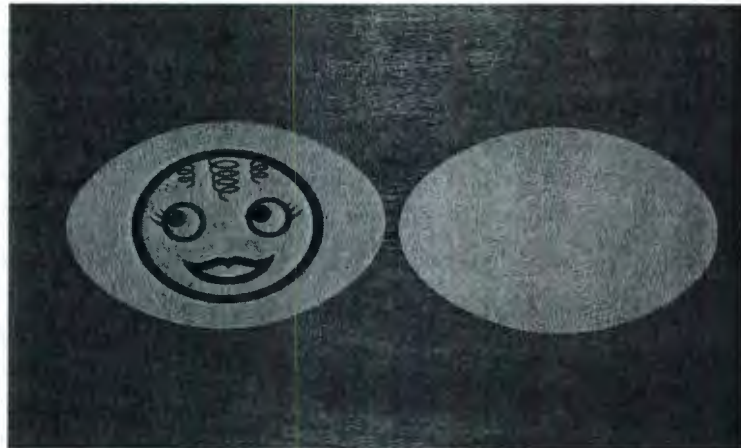


Figure 7. Photograph of the Peek-a-boo Patti cards (100% contrast card and blank card)

Autorefraction

Estimates of refractive error were determined with the Welch-Allyn SureSight hand-held autorefractor (Welch-Allyn, Skaneateles, N.Y., U.S.A). As shown in Figure 8, the tester placed the device in front of the child's face and imaged the child's pupil through the viewfinder. The tester was guided to the 35 cm calibrated testing distance by auditory cues emitted by the autorefractor. Within a few seconds, estimates were obtained for spherical refractive error (hyperopia or myopia), cylindrical refractive error (astigmatism), the axis of the astigmatism, as well as the reliability for the set of measurements. The average of two measurements was used as an estimate of refractive error for each eye. All refractions were conducted under dim light.



Figure 8. Photograph of a preschooler being tested with the Welch-Allyn SureSight autorefractor.

Ocular Alignment/Motility

All children were tested with the Hirschberg corneal reflex. As the child fixated on an optotype held by the tester approximately 40 cm away, the tester shone a penlight into the child's eyes. The tester then observed any asymmetry within the reflections from the two eyes, a result which would suggest misalignment of the eyes (i.e., strabismus). Second, ocular motility was examined in all children. Using the penlight as a target, eye movements were observed closely in the 9 fundamental directions (i.e., straight ahead, upward, downward, leftward, rightward, diagonally upward and rightward, diagonally downward and rightward, diagonally upward and leftward, and diagonally downward and leftward). Thirdly, opposing eye movements were examined by moving the penlight towards and away from the child's eyes and observing convergence and divergence of the eyes.

Ocular alignment in 2- and 3-year-olds was also evaluated with a more precise measure of misalignment, namely the distance cover-uncover test and the near cover-

Ocular alignment in 2- and 3-year-olds was also evaluated with a more precise measure of misalignment, namely the distance cover-uncover test and the near cover-uncover test. During the distance test, the child was instructed to fixate binocularly on a target approximately 3m away. One eye was then quickly covered with an occluder and the uncovered eye was observed for any movement, a result which would indicate that the eye is not fixating on the target and is therefore misaligned. A similar procedure was followed for the near cover-uncover test but instead, the target was approximately 40 cm away.

Stereopsis

Stereopsis/stereoacuity was assessed only if 2- and 3-year-olds were very cooperative. Most of the children within this age group were tested with the Randot E stereotest (see Figure 9). This test consists of three 8 x 10 cm plates; two random dot test plates and a demonstrator plate. One of the random dot plates is blank and the other has an "E" that can only be detected only if stereoacuity is present. The random dot test plate is designed so that when it is held at different distances from the child, the E represents different disparities. For example, when held at a distance of 1 m from the participant, the E subtends a relative depth of 250 arc sec. At 1.5m, the E subtends 168 arc sec.

To administer the test, the child was first shown the demonstrator plate that possessed a simple "E", a target which is easily visible to all as it does not require any stereopsis at all. The child was asked to identify the "E", but if the child could not correctly identify the letter, they were told that it was an "E". Polarized glasses were then placed on the child and the two random dot plates were held very close (20cm) to the

child so that they could easily locate the "E". Then the tester moved the plates back to 50 cm (relative depth equal to 500 arc sec) and instructed the child to point to the position of the "E". Once the location was correctly identified, the plates were shuffled and presented again to the child. The plates were presented 4 or 5 times at this distance and correct identification of the "E" on at least 4 of these trials was required to indicate that the child could detect an object of that relative depth. The tester then moved to the next test distance (1 m, relative depth of 250 arc sec) and followed the same procedure. If the child correctly identified the location of the "E" on at least 4 trials, the tester then moved to the next testing distance of 1.5 m (relative depth of 168 arc sec). The lowest disparity at which the child could correctly identify the location of the "E" was taken as an estimate of the child's stereoacuity.



Figure 9. Photograph of a child being tested with the Randot E Stereotest.

Some 3-year-olds were tested with the Randot Preschool Stereoacuity test, shown below in Figure 10 (Birch, Williams, Hunter & Lapa, 1997). The test consists of three

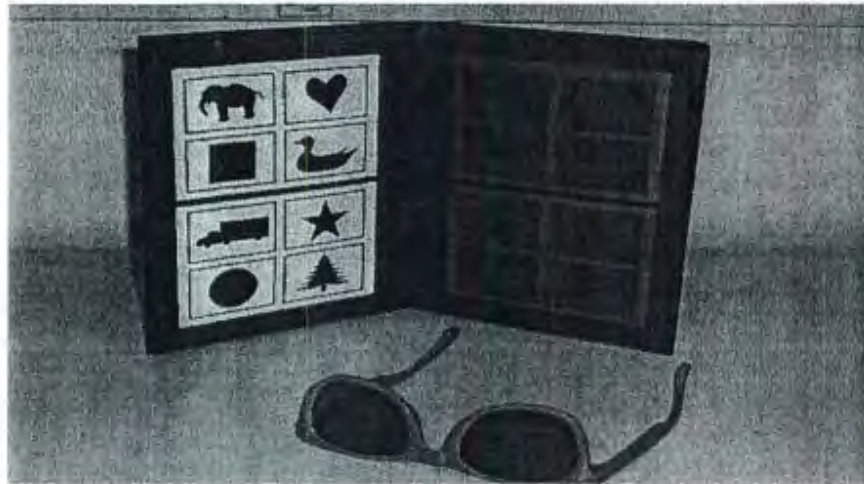


Figure 10. Photograph of one of the three books from the Randot E Preschool Stereoacuity test.

booklets. The left side of the book contains two sets of 4 pictures, (e.g., duck, tree, square, circle, etc.) The right side of each booklet contains 2 sets of four random dot patterns containing figures similar to those displayed on the left side. 3 of the 4 patterns contain stereofigures and the fourth pattern is blank. The three figures correspond to pictures on the left side of the book but are arranged in different order. To administer the test, the child was first asked to identify the obvious two-dimensional figures on the left side of the booklet. Then, wearing the polarized glasses, the child was shown the right side of book 1 which contains stereofigures of intermediate disparities (200 and 100 arc sec). The child was asked to identify the three stereofigures. If the child correctly identified 2 or 3 of the figures in book 1, testing continued with book 2 which contains stereofigures of finer disparities (60 and 40 arc sec). If the child could not correctly identify 2 or 3 of the stereofigures in book 1, testing continued with book 3, which contained figures of more coarse disparity (800 and 400 arc sec). The finest disparity

level at which the child could correctly identify 2 or 3 stereofigures was taken as an estimate of stereoacuity.

Results

Completion Rates and Completion Times

The primary objective of the present study was to identify an effective screening procedure for assessing, in a timely and efficient manner, the visual functioning of infants and toddlers. The second objective was to attempt to assess children on as many visual functions as possible. Table 3 categorizes children based on the number of tests completed successfully. To summarize the table, note that all of the 189 infants and children, completed at least one test, 95% completed 2 tests, and nearly half (48%) completed 4 tests. The values in the table were based on the following criteria: 6- and 12-month olds were deemed to have successfully completed the battery if the child completed a visual acuity test for each eye, the Hirschberg corneal reflex for each eye, autorefraction for each eye, and one test of contrast sensitivity for each eye (e.g., CS cards and/or Patti Pics contrast faces). 2- and 3-year-olds were said to have completed the entire battery if he/she completed a test of visual acuity for each eye, the Hirschberg corneal reflex for each eye, autorefraction for each eye, one test of contrast sensitivity for each eye, and a test of stereoacuity.

Overall, the completion rates for the entire screening battery were relatively low across all age groups with only 61 of the 189 children (32%) completing the screening battery (see in the asterisks in Table 3). Comparing across all age groups, completion

rates were highest for 6-month olds with nearly half (48%) completing the 4 tests in their respective battery. In contrast, only 10 of the 60 24-month-olds (17%) successfully completed the entire battery. Overall, Table 3 shows that the proportion of 12- and 24-month-olds completing 3, 4, and 5 tests was consistently lower than that of all the other age groups. The lower rates for 12- and 24-month-olds reflect the difficulty testers experienced with these children, notably the increased agitation caused by monocular occlusion, attentional waning, and/or fatigue.

Table 3. Number and cumulative percentage (in bold) of children successfully completing tests within the screening battery, categorized by age.

	Age				Total (all ages)
	6	12	24	36	
Completed at least 1 test	29/29 100%	37/37 100%	60/60 100%	63/63 100%	189/189 100%
Completed at least 2 tests	29/29 100%	35/37 95%	56/60 93%	59/63 94%	179/189 95%
Completed at least 3 tests	24/29 86%	30/37 81%	36/60 60%	52/63 82%	143/189 76%
Completed at least 4 tests	14/29* 48%	13/37* 35%	20/60 33%	43/63 68%	90/189 48%
Completed 5 tests	N/A	N/A	10/60* 17%	24/63* 38%	34/123 28%

Note: * denotes children who completed all tests for their respective age groups.

To evaluate the success of the screening battery more precisely, completion rates are shown separately for each test in Table 4, and are categorized again by age. As the Table illustrates, tests of autorefraction and ocular alignment (Hirschberg corneal reflex) yielded very high completion rates across all age groups (both 94% overall). The

Table 4. Completion rates and percentages (in bold) for each test of visual function in the screening battery, categorized by age. Note that for tests of visual acuity, refractive error, ocular alignment, and contrast sensitivity, successful completion refers to complete testing of **both** eyes.

	Age (months)				
	6	12	24	36	Total
Visual Function					
Visual Acuity	25/29 86%	28/37 76%	38/60 63%	50/63 79%	141/189 75%
Refractive Error	28/29 97%	35/37 95%	56/60 93%	59/63 94%	178/189 94%
Contrast Sensitivity*	15/29 52%	15/37 41%	15/60 25%	27/63 43%	72/189 38%
CS Cards/Booklet	8/29 28%	4/37 11%	15/60 25%	27/63 43%	54/189 29%
Peek-a-boo faces	10/29 34%	13/37 35%	N/A	N/A	23/66 35%
Ocular Alignment (Hirschberg)	28/29 97%	36/37 97%	58/60 97%	56/63 89%	178/189 94%
Stereoacuity	N/A	N/A	14/60 23%	50/63 79%	64/123 52%
Complete Screening Battery**	14/29 48%	13/37 35%	10/60 17%	24/63 38%	61/189 32%
Completion Time for Entire Battery	13.8 min	14.6 min	9.2 min	13.6 min	12.8 min
Acuity + Refractive Error + Alignment Combination	24/29 83%	26/37 70%	37/60 62%	45/63 71%	132/189 70%

* Note that some children completed both the Peek-a-boo faces contrast test in addition to the CS card or booklet procedure. Also, in the case of 2- and 3-year olds, CS assessment was first attempted with the CS card or booklet test. However, only if time permitted and if the child was attentive was assessment with the Peek-a-boo test attempted. Given this constraint, these data are not reported here.

** 6- and 12-month-old assessment was considered complete if the child completed the TAC, any test of contrast sensitivity, the Hirschberg corneal reflex, and autorefraction for both eyes. Assessment in 24- and 36-month-olds was considered complete if the child finished any visual acuity test for both eyes, the Hirschberg corneal reflex for both eyes, autorefraction for both eyes, and any test of stereoacuity and any test of contrast sensitivity for both eyes.

extremely high completion rates for these tests likely reflects the minimal attentional demands placed on the child. Compared to other tests in the screening battery, both autorefraction and the Hirschberg corneal reflex were completed very rapidly, typically within 1-2 minutes per test for both eyes. At the other extreme, measures of stereoacuity were attempted only in the older two age groups, and the notably low completion rate for 24-month-olds (23%) likely reflects the lack of comprehension of the task or its complexity. However, among older 36-month-olds, tests of stereoacuity were much more successful, with 50 of the 63 children (79%) completing a test of stereoacuity. 75% of all children successfully completed a test of visual acuity. All tests of acuity required approximately the same amount of time (about 4 to 6 minutes to test both eyes) and these tests were relatively easy to administer. Except for 24-month-olds (63% completion rate) who appeared to be particularly distracted by the wearing of occluding glasses, tests of monocular visual acuity were very successful, with 6-month-olds recording the highest completion rate (86%). 12- and 36-month-olds recorded comparable completion rates of 76% and 79%, respectively.

Similar problems with monocular occlusion were also encountered with the CS cards, the CS booklet, and the Peek-a-boo faces contrast test. Compared to all other tests, the CS cards and CS booklet required considerably more time to complete and thus, placed considerable attentional demands upon the child. Therefore, completion rates for contrast sensitivity (38% overall) were low across all age groups. Early in the screening program, it was established that the CS cards were extremely time consuming for the 6- and 12-month-old infants. Therefore, from that point onward, the Peek-a-boo faces

contrast test was always administered prior to the CS cards to help ensure that at least one measure of CS was obtained. The Peek-a-boo faces contrast test required less time than the card procedure but still only 34% of 6-month-olds and 35% of 12-month-olds successfully completing the faces test. Even fewer 6-month-olds (28%) and 12-month-olds (11%) completed the CS card procedure. The lower completion rate with the CS cards is likely a direct reflection of the time it took to administer the test, as well as the fact that it was typically administered at the end of the screening session. Thus, given these constraints, the difference in completion rates between the CS cards and the Peek-a-boo faces contrast test should not be taken as a direct comparison between the two tests. In all, 52% of 6-month-olds and 41% of 12-month-olds completed a measure of contrast sensitivity, with only three 6-month-olds and two 12-month-olds completing both the contrast faces test and the CS cards.

Given that a sine-wave-based test provides a much more detailed description of contrast sensitivity, contrast sensitivity in 24- and 36-month-olds was assessed with the CS card or booklet procedures only. 25% of 24-month-olds and 43% of 36-month-olds completed CS testing, with 24-month-olds again recording the lowest completion rate across all age groups. To analyze these data formally, statistical analysis was conducted to determine whether completion rates varied significantly across tests. Test variables were coded based on whether a child completed or failed to complete a test. A chi-square analysis revealed that the differences observed between the completion rates for individual tests were significant ($\chi^2 = 223.96$, $df = 1$, $p < .001$). This difference is largely attributable to the very high completion rates for tests of acuity, refraction, and ocular

alignment compared to the relatively low completion rate for tests of contrast sensitivity and stereoacuity.

Despite the usefulness and success of the CS cards/booklet when used alone (Adams & Courage, 1993; Drover et al., 2002; Drover, Courage, Dalton & Adams, 2006), the low completion rates here suggest it may not be ideal within a screening setting. Furthermore, in pilot work, we found that all 24- and 36-month-olds who completed the Peek-a-boo Patti faces contrast test, easily passed the test, which suggests that this test is not a sensitive screening tool, at least among the older age groups. Given these findings, the completion rates for the screening battery were recalculated by omitting CS tests and including only the 3-test combination of visual acuity, autorefraction, and ocular alignment. With CS removed, the overall completion rate improved from 32% to 70%, with substantial improvement across all age groups. These results are shown in the last row of Table 4 and reveal that 6-month-olds demonstrated the highest completion rate (83%), with 12, 24, and 36-month-olds all showing slightly lower rates of 70%, 62%, and 71% respectively. Additionally, although these three tests are typically administered with relative ease and are not overly time consuming, the 3-test completion rates recorded here may have been even higher had the more difficult tests not been included in the battery. This is because some of the more difficult tests (i.e., contrast sensitivity, stereoacuity) were often attempted before tests of acuity, alignment or autorefraction and thus, completion rates may reflect the general fatigue, distress, or attentional waning attributable to the CS/stereoacuity procedures.

A final result of interest was to determine whether completion rates for each test varied significantly across age. To analyze this, logistic regression was conducted for each test. Similar to ANOVA, a logistic regression is a generalized linear model that allows for the prediction of a dichotomous dependant variable (as in this case, either one's ability to complete or to not complete a test), from a predictor variable (i.e., one's age). The results of the logistic regression revealed that for the 4 tests attempted in all age groups (visual acuity, autorefraction, Hirschberg corneal reflex, and contrast sensitivity) there was no significant difference across age. Therefore, although the rates of completion fluctuate across age, the differences are slight, and all tests utilized in the present study were equally successful/unsuccessful at all ages.

Mean times for the completion of the entire battery are provided in the second to last row of Table 4. An analysis of variance revealed that there was a significant difference in completion time between groups ($F = 124.4$, $df = 3$; $p < .001$). Scheffe post-hoc tests revealed that the completion times for 24-month-olds ($M = 9.2$ min) were significantly faster than those for all other age groups ($p < .05$), and that the rest of the groups showed comparable average completion times, ranging from 13.6 to 14.6 minutes.

Visual Development

Another objective of this study was to assess visual development occurring during the critical stage from 6- to 36-months of age. We hoped to gain insight into the development of several key visual functions known to go through substantial improvements during the first years of life. As well, to validate the tests used within the

present screening battery, the values obtained here were compared to those from previous studies.

Visual Acuity

Table 5 provides, in Log MAR notation, the mean monocular visual acuities and the standard deviations (SD) for each age group. The findings indicate a small improvement in visual acuity from 6-months ($M = 0.85$ LogMar, $SD = 0.22$) to 12-months of age ($M = 0.74$ LogMar, $SD = 0.16$). Acuity then improved to 0.32 LogMar ($SD = 0.12$) at 24-months and then remains unchanged at 36-months ($M = 0.32$ LogMar, $SD = 0.10$). A one-way analysis of variance revealed that there was a significant difference in mean acuity across age ($F = 123.6$, $df = 3$, $p < 0.001$). Scheffe post-hoc analysis revealed that acuity did not differ between 6- and 12-month-olds, but improved between 12- and 24-months ($p < 0.05$). Furthermore, as Figure 11 shows, the results compare well with previous norms, as the current acuity means fall within one standard deviation of previous TAC normative values (Courage and Adams, 1990).

Table 5. Visual acuity test results.

Age	N	Mean Acuity (LogMAR)	SD	Snellen Equivalent (approx.)
6 months	26	.85	.22	20/143
12 months	35	.74	.16	20/100
24 months	40	.32	.12	20/40
36 months	50	.32	.10	20/ 40

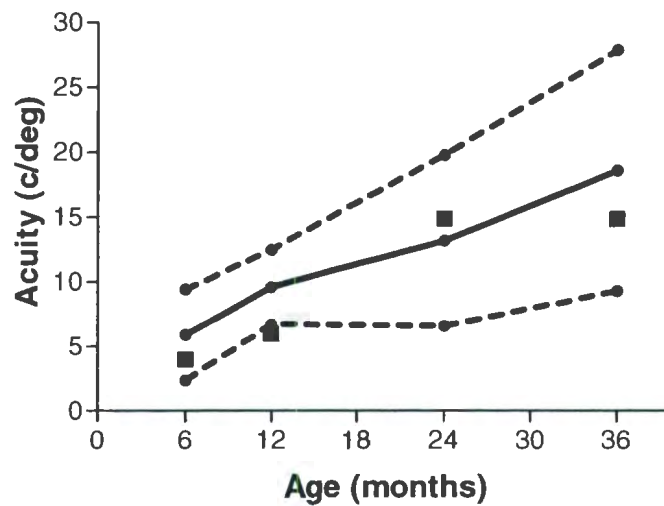


Figure 11. Visual acuity means from the present study (black squares) relative to normative means (solid black line) taken from Courage & Adams, 1990. The upper and lower broken lines on the graph represent one standard deviation above and below the normative means across age.

Refractive Error

At least one reliable estimate of refractive error was obtained from each eye of most children (94%). If two measures were obtained, the mean across trials was used for analysis. Cylindrical refractive error estimates showed considerable variation both within and across age groups (Figure 12). Mean cylinder decreased from 1.35D (SD = 0.75D) at 6-months to 0.94D (SD = 0.58D) at 12-months and then again to 0.67D (SD = 0.60D) at 24-months. However, there was very little change in cylindrical error at 36-months ($M = 0.72D$, $SD = 0.41D$). Figure 13 shows that the reduction in cylindrical refractive error observed in the present study corresponds with values obtained in previously conducted studies of both autorefraction and cycloplegic photorefraction (Adams et al., 2002; Chan & Edwards, 1993; Saunders, 1995).

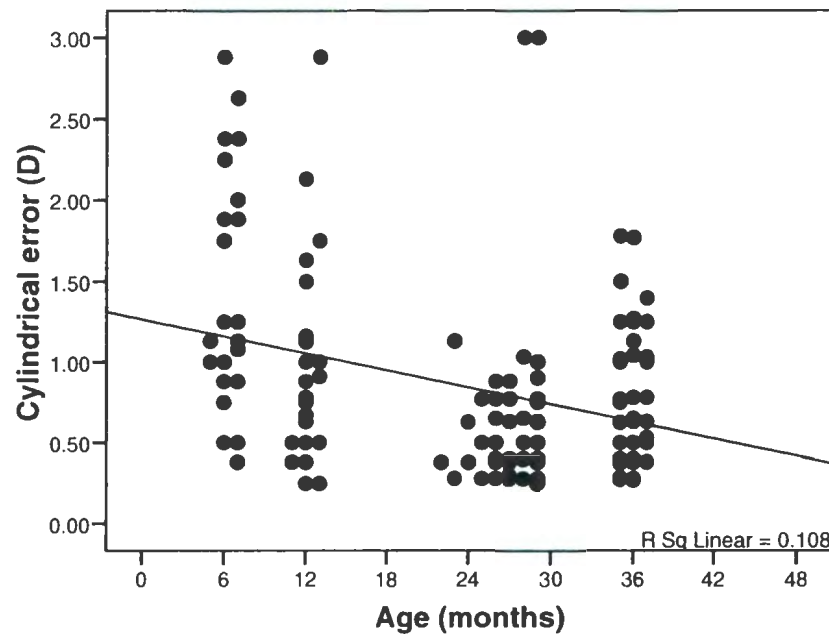


Figure 12. Scatterplot (with regression line) showing individual cylindrical refractive error estimates (in diopters) obtained from the right eye of 6- to 36-month-old children.

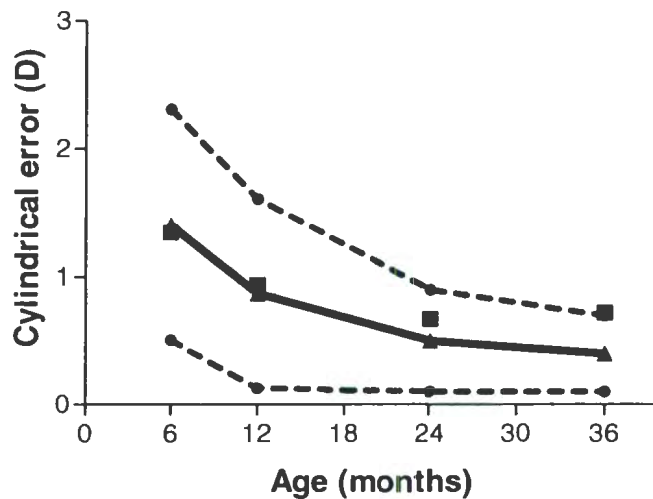


Figure 13. Mean cylindrical refractive error (in diopters) from the right eyes of children in the present study (black squares) relative to previously determined normative means across age (solid black line; Adams et al., 2002). The broken lines on the graph represent one SD above and below the normative means.

Concerning the spherical component of refractive error, the regression line in Figure 14 shows that the individual spherical estimates appear to change minimally with age, and Figure 15 shows that the mean spherical error obtained in the present study concur well with previously published values from both autorefraction and cycloplegic photorefraction (Adams et al., 2002; Chan & Edwards, 1993). On average, infants and young children within this age range are slightly hyperopic with an average spherical error of $+0.98\text{D}$.

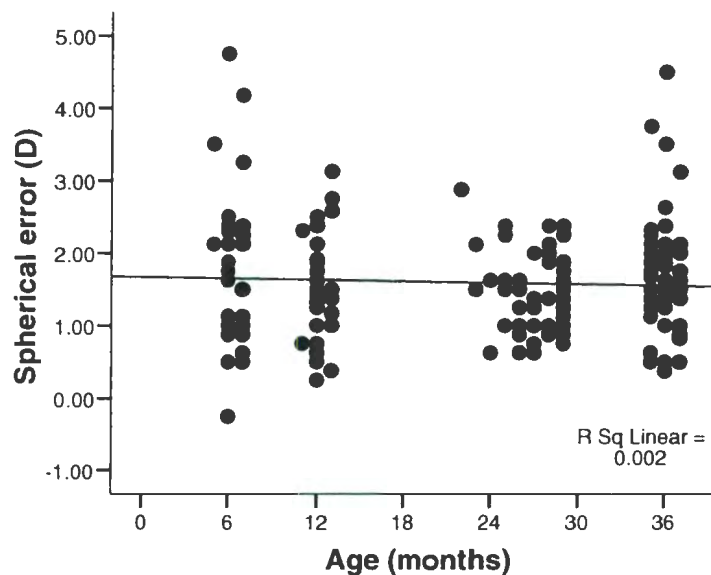


Figure 14. Scatterplot (with regression line) showing individual spherical refractive error estimates (in diopters) obtained from the right eyes of 6- to 36-month-old children.

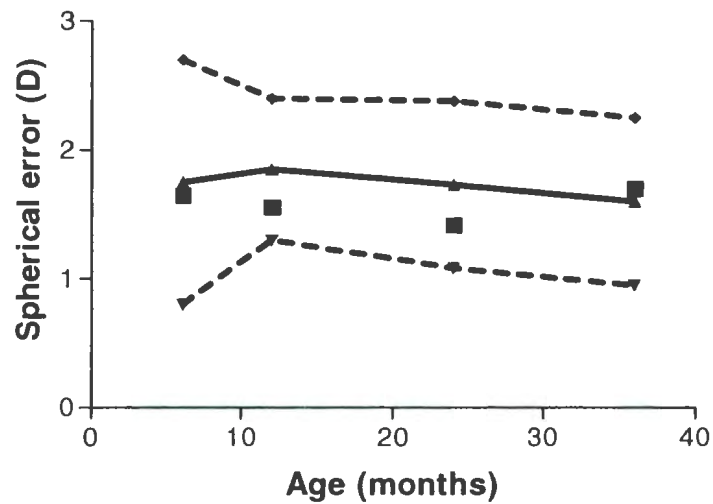


Figure 15. Mean spherical refractive error (in diopters) from the right eyes of children in the present study (black squares) relative to previously determined normative means across age (black line; Adams et al., 2002). The broken lines on the graph represent one SD above and below the normative means.

Contrast Sensitivity

Figure 16 shows the mean contrast sensitivity functions for 24- and 36-month olds in the present study and revealed that sensitivity improves slightly at mid- to high spatial frequencies between 24- and 36-months, a result which suggests a progressive increase in maximum spatial resolution. As discussed previously, 6- and 12-month infants proved extremely difficult to test and therefore, contrast sensitivity was estimated using the Peek-a-boo faces contrast test. The results reveal slight improvement in contrast sensitivity with age. 12-month-olds detected slightly lower contrast levels ($M = 11.6\%$, $SD = 2.6$) than 6-month-olds ($M = 12.5\%$, $SD = 3.3$), the differences observed between these two age groups was not significant.

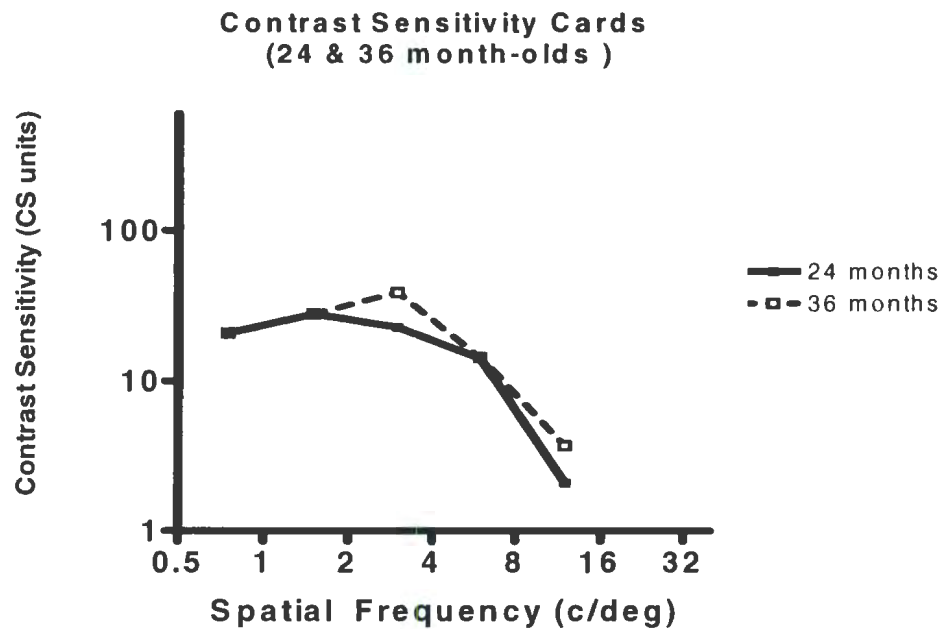


Figure 16. Contrast sensitivity functions (CSFs) for 24- and 36-month-olds tested with the contrast sensitivity cards.

Stereopsis

Mean stereoacuity improved from 270 arc sec (SD = 177) at 24-months to 233 arc sec (SD = 140) at 36-months. Despite notable variability within each of these age groups, the results obtained here concur well with previous research conducted at this age (Birch et al., 1997).

Prevalence of Visual Abnormalities Detected During Screening

The success of the screening battery relies heavily on its effectiveness and its ability to correctly identify possible impairments and/or risk factors. To further validate individual tests and the entire screening battery, the number of possible abnormalities

detected in the present study were compared to established criteria. The present study was the first to implement infants into a comprehensive screening battery; thus, estimates of possible visual impairments are an important first step in constructing reliable norms and potential referral criteria for this under-studied population. To determine whether a child was within the range of healthy visual functioning, test scores from the present study were compared to previously documented norms for each age group (Hope & Maslin, 1990; Manny, Martinez, & Fern, 1991; Molgaard, Biering-Sorensen, Michelsen, Elmer, & Rydberg, 1984; Reinecke & Simons, 1974; Courage, Drover, Vernescu, Keough, & Adams, 2001; Courage & Adams, 1990; Atkinson et al., 1996; Adams et al., 2002; Williams, Harrad, Harvey, Sparrow, ALSPAC Study Team, 2001; Anker et al., & Wade, 2003; Anker, Atkinson, Braddick, Nardini, & Ehrlich, 2004).

It was difficult to establish referral criteria for autorefraction as the technology is still relatively new. Thus, criteria for 2- and 3-year-olds was based on the only published early normative study for the Welch Allyn SureSight autorefractor (Courage et al., 2001; Drover, Kean, Courage, & Adams, 2008). Establishing criteria for infants was further complicated by the fact that even less data are available for the first year of life. Therefore, referral criteria for infants was based on previous research conducted within our lab (Adams et al., 2002) as well as the criteria used within large-scale infant vision screening programs that have employed other non-cycloplegic techniques, such as photorefraction (Williams et al., 2001; Atkinson et al., 1996) and videorefraction (Anker, et al., 2003; Anker et al., 2004; Atkinson et al., 1996). Similarly, the present study is among the first to implement measures of contrast sensitivity within a screening battery.

Referral criteria for CS in 2- and 3-year-olds was therefore based on results from previous CS card and booklet research within this age group (Adams & Courage, 1993; Adams & Courage, 1996; Adams & Courage, 2002; Drover et al., 2006; Drover et al., 2008). The present study did not develop CS referral criteria for 6- to 12-month-olds due to the limited data obtained from these groups.

Referral criteria for visual acuity was based on previous research as well as the recommendations of major North American pediatric/vision organizations (Courage & Adams, 1990; Mayer, Beiser, Warner, Pratt, Raye, & Lang, 1995; Hall et al., 2000; Courage & Adams, 1990; American Academy of Pediatrics, American Academy of Ophthalmology). Likewise, the referral criteria for the Randot Preschool and the Randot E was based on well established criteria for 2- and 3-year-olds (Hope & Maslin, 1990; Manny, Martinez, & Fern, 1991). Details of the criteria used in the present study to define a visual abnormality for each measure and age group are provided in Table 6. The referral criterion for contrast sensitivity in 2- and 3-year-olds are provided in Tables 7 and 8 for the CS cards and booklet respectively (Drover et al., 2002). As the Peek-a-boo low contrast test is new, there is currently no normative data or referral criteria available.

Table 6. Possible ocular diagnosis and referral criteria for each test and age group.

Possible Disorder	Test	Age (months)	Criteria
Reduced Visual Acuity	Teller Acuity Cards	6	< 2.4 c/deg and/or ≥ 1 octave difference* between eyes
	Teller Acuity Cards	12	< 3.8 c/deg and/or ≥ 1 octave difference between eyes
	PattiPics Cards	24	< 20/50 and/or ≥ 2 line difference** between eyes
	PattiPics Linear Optotypes		< 20/80 and/or ≥ 2 line difference between eyes
	PattiPics Cards	36	< 20/40 and/or ≥ 2 line difference between eyes
	PattiPics Linear Optotypes		< 20/63 and/or ≥ 2 line difference between eyes
Motility/Fixation Disorder	Hirschberg Corneal Reflex	6-36	Any asymmetry in the corneal reflex
Reduced Stereoacuity	Randot E	24-36	> 500 arc sec
	Randot Preschool Stereoacuity Test	24-36	> 400 arc sec
Significant Refractive Error	Autorefraction		
	Astigmatism	6-12	> 2.75 D
		24-36	> 1.50 D
	Hyperopia	6-36	> 3.50 D
	Myopia	6-12	> 2.00 D
		24-36	> 1.00 D
	Anisometropia	6-12	> 1.75 D
		24-36	> 1.75 D

*1 octave refers to the doubling or halving of spatial frequency

** A line refers to a line on the Patti Pics Linear Optotype test. Each line represents a difference of 0.1 LogMar

Table 7. Referral criteria in CS units for each spatial frequency of the CS cards.

	Spatial Frequency (c/deg)				
	0.75	1.5	3	6	12
Age					
24 months	20.8	27.8	16.9	3.2	1.8
36 months	20.8	27.8	38.5	11.4	3.2

Table 8. Referral criteria in CS units for each spatial frequency of the CS booklet.

	Spatial Frequency (c/deg)				
	0.75	1.5	3	6	12
Age					
24 months	27.8	41.7	52.6	6.4	3.3
36 months	37	83.3	83.3	26.3	3.3

Table 9 provides the number of children who fell below the criterion for each test, categorized by age. It is important to note that the children who were detected as positive by the screening were referred to an ophthalmologist or optometrist for a gold standard eye/vision exam. Unfortunately, the results of the gold standard exam were not available to confirm the screening results. Overall, 24% (N= 43) of the children who attempted the screening battery were identified as having some form of possible visual abnormality. Among the different age groups 12-, 24-, and 36-month-olds had comparable frequencies (17% to 21%). However, 53% of the 6-month-olds demonstrated some form of possible

visual abnormality. In Canada, the prevalence rate for visual disorders among children between the ages of 2 and 5 years is estimated to be between 10% and 15% (Drover et al., 2008; Robinson, Bobier, Martin, & Bryant, 1999). With the exclusion of 6-month-olds, the results obtained here concur well with the estimated prevalence rates.

Table 9. Frequency (percent in bold) of visual abnormalities detected for each visual function at each age during screening.

Visual Disorder	Number and Percent of Cases Detected				Total
	Age				
	6	12	24	36	
Reduced Visual Acuity	4/25 16%	2/28 7%	1/38 3%	1/50 2%	8/141 6%
Motility/Fixation Disorder	2/28 7%	1/36 3%	3/58 5%	3/56 5%	9/178 5%
Reduced Stereoacuity	--	--	1/14 7%	2/50 4%	3/64 5%
Significant Refractive Error	9/28 32%	3/35 9%	7/56 12%	4/59 7%	23/178 13%
Astigmatism	2/28 7%	2/35 6%	4/56 7%	1/59 2%	9/178 7%
Hyperopia	5/28 18%	0	2/56 4%	2/59 3%	9/178 5%
Myopia	--	--	--	--	
Anisometropia	2/28 7%	1/35 3%	1/56 2%	1/59 2%	5/178 3%
All Disorders	15/28 53%	6/35 17%	12/56 21%	10/59 17%	43/178 24%

The most frequently occurring visual abnormality detected during screening was significant refractive error, 13% of the children showing a refractive estimate outside the normal range for his/her age. Significant refractive error is often found to be the most frequently occurring abnormality detected during pediatric eye screening, and has an estimated prevalence in older preschool children between 6% and 8% (Drover et al., 2008; Donnelly, Stewart, & Hollinger, 2005). Notably, 32% of 6-month-olds were identified as having significant refractive error compared to 7-12%, for the 12-, 24-, and 36-month-olds. Although these rates (especially among 6-month-olds) are slightly higher than anticipated, it is important to note that the current sample is younger than that used to establish prevalence estimates.

It was anticipated that infants would demonstrate higher levels of refractive error than toddlers, with refractive error decreasing across ages. As anticipated, the results across ages demonstrate this developmental trend as mean cylindrical error reduced from 1.35D (SD = 0.75D) at 6-months to 0.72D (SD = 0.72D) at 36-months. The high rate of refractive error may also be partially attributable to the lenient criteria. As noted, autorefraction criteria was based on a combination of recent SureSight research with the results from mass infant screening programs employing alternative non-cycloplegic methods, namely videorefraction and photorefraction (Anker et al., 2003; Atkinson et al., 1996). Thus, the results here should be interpreted with caution and suggest the need for stricter criteria for the autorefractor. The rates of astigmatism, hyperopia, and anisotropia among all age groups, albeit lower than those for 6-month-olds, are also slightly higher than established prevalence rates, which are estimated to be between 3-

7%, 3-6.5% and, 1 - 3.6% respectively among 2 to 4 year-olds (Drover et al., 2008; Junghans & Crewther, 2003; Cowen & Bobier, 2003; Donnelly et al., 2005; Mayer et al., 2001; Preslan & Novak, 1998). Among infants, the estimated prevalence of significant refractive errors, including hyperopia, myopia and anisometropia have been estimated to be between 7 - 10%.

To analyze these prevalence data statistically, a logistic regression was conducted to compare individual visual abnormalities across age. The analysis revealed that reduced visual acuity ($W = 4.06$; $p < .05$) and significant refractive error ($W = 5.8$; $p < .05$) varied with age, with reduced visual acuity and significant refractive error occurring most frequently in 6-month-olds and least frequently in 36-month-olds. Abnormalities in other visual functions did not vary across age.

Discussion

The present study had several objectives. Our primary goal was to develop and test the feasibility of a screening battery that could be used to assess the visual functioning in infants and very young children. Screening programs aimed at detecting visual disorders in childhood typically target children between the ages of 3 and 6, and very few have attempted to implement programs for younger children, especially infants. To our knowledge, no other study has attempted such a comprehensive screening procedure in infants and toddlers, an age group that traditionally has been particularly difficult to test. Previous attempts have relied heavily on cumbersome and time-consuming technologies (i.e., cycloplegic refraction) and/or have limited "screening" to single estimates of visual functioning rather than comprehensive test batteries.

The present study was successful in demonstrating that children between the ages of 6-months and 3-years can be tested on several aspects of visual functioning in a fairly effective and efficient manner. The results of the present study are among the first to indicate that very young children can be tested within a timeframe similar to older children. The average time for completing the battery was 12.8 minutes, with the infant groups requiring about 14 minutes, due to greater time requirements between tests. Additionally, during tests requiring monocular occlusion, a substantial proportion of testing time was required to place and replace the glasses on the younger children. It is difficult to put these data into perspective as the majority of completion time data comes from infant studies in which only a single measure of visual functioning was assessed. However, a recent study conducted by our group found that, in 2 to 5-year-olds, the average completion time for a similar screening battery was 11.6 minutes (Drover et al., 2008). The times recorded in the present study suggest that infants and very young children can complete a comprehensive screening battery within a similar time period. It is important to note that certain tests took substantially more time to complete. Similar to previous screening studies conducted in older preschoolers (Drover et al., 2008), the CS cards and booklet had the longest completion time of any measure. Likewise, this longer completion time of CS tests likely impacted the overall rate of completion. On the contrary, the success (70% completion rate) of the 3-measure combination, which includes autorefraction, visual acuity and the Hirschberg corneal reflex, reflects the ease with which all these tests could be administered. Recent research using a similar battery of tests revealed that the average completion time for this 3-measure combination for 2-

year-olds was 5.3 minutes (Drover et al., 2008). Although we did not time individual tests, we estimate that infants in the present study completed this test combination in about 5 to 7 minutes, a result that is particularly encouraging.

Data regarding completion rates for a screening battery are also minimal and no data exist for children under the age of 2. Thus, the present study is among the first to provide data for a multi-test screening battery. Though the completion rates for the entire battery were low across all ages, significant attentional demand was placed on children in order to complete the 4 or 5 required tests. Nonetheless, the results are encouraging. Previous research with this age group has focused on fewer tests for toddlers and preschoolers, and just single measures for infants (Enzenauer, Freeman, Larson, & Williams, 2000; Atkinson, Braddick, Robier, Ehrlich, King, Watson, & Moore, 1996). Thus, the results of the present study reveal that comparable completion rates can be obtained with multiple tests of visual functioning. All children in the present study completed at least one measure, 95% completed 2 measures, and 76% successfully completed three measures. Furthermore, statistical analysis revealed that completion rates for age groups did not differ significantly, therefore, the tests within the screening battery were equally successful for all groups and the battery is equivalent across age, at least in terms of practicality and time-efficiency. There were certain factors which contributed to children not completing the battery. For instance, monocular occlusion was particularly difficult with 12- and 24-month-olds. Additionally, fatigue and attentional waning likely contributed to the low completion rate. Also, 24-month-olds demonstrated considerable

difficulty with tests of stereoacuity, with only 23% successfully completed a test of stereoacuity compared to 79% of 36-month-olds.

Given the limitations mentioned above, completion rates for the screening battery may not truly reflect the testability of the children, or the usefulness of individual tests. To take into account the possibility that individual tests (notably CS and stereoacuity) may account for the low completion rates for all age groups, completion rates were re-calculated for the three-test combination of visual acuity, autorefraction and ocular alignment. With CS and stereoacuity eliminated, the overall completion rate improved dramatically from 32% to 70%. These findings suggest that implementing tests of stereoacuity and contrast sensitivity within a single-session is very challenging for infants and young children. Additionally, and as mentioned above, the problem with measures of CS is likely not the complexity of the task but the length of the test. When used within a screening battery with 2 - 5 year olds, the CS cards and booklet require approximately 3 to 6 minutes to complete (Drover et al., 2008). Moreover, when used singly with infants the CS cards have an average completion time of 6.5 minutes for infants between 3.5 and 12-months (Drover et al., 2002).

Newer methods such as hand-held autorefractors and measures of contrast sensitivity have yet to be implemented into any mass screening program and, therefore, the usefulness of these methods as part of a collection of tests has yet to be established. From a clinical perspective, such information is critical, as the objective of screening is to obtain a thorough and wide-ranging assessment of visual functioning. The present study represents the first to combine within a screening program, standard screening tests (e.g.,

TAC, Randot Stereoacuity) with newer methods (e.g., CS cards, Peek-a-boo contrast faces) that have potential, but have yet to be used.

In addition to the minimal data available regarding the usefulness of vision assessment tools with very young children, data are also lacking in terms of development of visual functions, particularly measures obtained from newer techniques and technologies. It was a further objective of this study to compare the results obtained here, to previous data obtained from alternative methods of assessment. The following sections outline both the usefulness of each method within the battery, and comparison of our results with the available developmental findings.

Visual Acuity

Spatial vision is considered the most important of all visual functions and is assessed typically with a measure of visual acuity. Tests such as the Teller Acuity Cards, and optotype tests such as the Snellen E and the Patti Pics Symbols charts, are considered standard procedures for assessing early visual acuity. 75% of all children who attempted the screening battery completed a measure of visual acuity for each eye. 24- and 36-month-olds were assessed using the Patti Pics optotype chart or the Patti Pics isolated symbols book. These tests were easy to administer and yielded satisfactory completion rates for both age groups. 63% of 24-month-olds and 79% of 36-month-olds successfully completed a test of visual acuity in each eye, with the lower rate for 24-month-olds likely accounted for by difficulties with monocular occlusion. Visual acuity in 6- and 12-month-olds was assessed with the Teller Acuity Cards. The procedure proved highly

successful, with 86% of 6-month-olds and 76% of 12-month-olds completing the test. The Teller Acuity Cards have been validated as a fast and accurate means of assessing spatial vision in preverbal and nonverbal populations. This test has become standard within pediatric clinical settings and normative values for this measure have been established from infancy through adulthood (Teller, McDonald, Preston, Sebris & Dobson, 1986; Mohn, van Hof-van Duin, Fetter, de Groot, Hage, 1988; Courage & Adams, 1990). In general, visual acuity is known to improve substantially during the first year of life with more gradual development thereafter (Mayer et al., 1995; Courage & Adams, 1990; Teller et al., 1986; Dobson & Teller, 1978; Mayer & Dobson, 1982; Birch, et al., 1982). The results of the present study reflect this developmental trend, with a slight improvement between 6- and 12-months, significant improvement between 12- and 24-months, and then little change at 36-months.

Amblyopia is defined as a reduction in spatial vision and thus tests of visual acuity are considered fundamental for detecting amblyopia and the associated risk factors. Early detection of reduced visual acuity is considered crucial to treatment success and the recovery of visual acuity loss. 6% of all children tested here showed reduced visual acuity. The highest rate occurred in 6-month-olds, with 4 of the 25 children (16%) demonstrating reduced visual acuity for their age group. The prevalence of acuity deficits appeared to decrease with age, with 7% of 12-month-olds demonstrating possible visual acuity impairments, and only 3% and 2% of 24- and 36-month-olds respectively. These values are slightly higher than those reported previously for 2 to 5 year-olds (Drover et. al., 2008). The higher than anticipated rate of reduced

visual acuity among 6- and 12-month-olds may be explained by several factors. First of all, the sample sizes for both groups were relatively small ($n = 29$; $n = 37$). Considerably more children would need to be screened in order to calculate true prevalence rates. Additionally, the values obtained in the present study were compared to normative values established during sessions in which the TAC was the only test administered. Most children involved in the present study completed multiple tests. Therefore, the higher than anticipated rates of reduced acuity may be explained by attentional factors. Furthermore, the significantly higher prevalence of acuity deficits with this age group are likely explained by developmental variability. Research suggests that early estimates of Teller acuity may not be predictive of later visual functioning (Courage & Adams, 1990; Hall et al., 2000; Mash & Dobson, 1998). While it is likely that 6- and 12-month-olds that scored within the normal range for their age group will likely maintain normal visual acuity throughout development, the results from abnormal children are less certain. Researchers and clinicians agree that while the TAC is useful for predicting normal development, drawing conclusions based on abnormal results should be done with caution and diagnosis should not depend on this measure alone (Spierer, Royzman, Chetrit, Novikov & Barkay, 1999; Mash, Dobson & Carpenter, 1995). The limitations of the Teller Acuity Cards along with the increased emphasis on early identification of visual impairments during the critical period of development have highlighted the need for a more comprehensive measure of spatial vision.

Contrast Sensitivity

Measures of contrast sensitivity provide a more complete index of spatial vision by assessing an individual's ability to detect targets of varying size (spatial frequency) and contrast and, thus, providing a more accurate depiction of one's visual functioning with real world objects. The shape of an individual's contrast sensitivity function (CSF) is particularly useful as it provides some information about anatomical and physiological mechanisms within the central system (Banks & Salapatek, 1981; Adams & Courage, 2002). Likewise, from a clinical perspective, deviations within certain frequencies of the CSF curve provide insight into the nature of the possible underlying impairments.

All 24- and 36-month-olds in the present study attempted the CS card and/or booklet procedure. However, only 25% of 24-month-olds and 43% of 36-month-olds successfully completed a measure for each eye. It was established early on in the study that the CS cards were extremely time consuming for 6- and 12-month-olds. Therefore, the majority of 6- and 12-month-olds were assessed only with the Peek-a-boo faces contrast test and only if the child was still cooperative and after all other tests were completed, was the card procedure even attempted. Only 28% of 6-month-olds and 11% of 12-month-olds completed the CS card procedure. The completion rates were less than satisfactory. Nonetheless, this study is the first to test the usefulness of the Peek-a-boo faces contrast test and the CS card procedure with infants in a screening study. The Peek-a-boo faces contrast test was extremely conducive to the screening setting and could be completed within 2 to 3 minutes. However, the information provided by the CS card procedure is far more informative than that of the faces test. Unlike the CS cards, the Peek-a-boo faces contrast test only assesses the child's ability to detect objects of varying

contrast but not across different spatial frequencies. Therefore, in order to capture a complete profile of a child's spatial vision, the test would have to be redeveloped/redesigned to vary the size (SF) of the targets. In this way, the test may be more useful clinically, as one could then construct a complete CSF. Given that the CSF also provides a visual acuity estimate, CS measures hold particular promise for screening as they could potentially limit the number of tests administered and, thus, increase the efficiency of the battery. One potential modification may be to test children with fewer spatial frequencies.

Despite this limitation only 4 of the 42 (9%) 24- and 36-month-olds tested with the CS cards scored below referral criteria. This concurs with a previous preschool screening study in which reported prevalence rates of contrast sensitivity deficits were low (Drover et al., 2008). Additionally, a number of studies have shown that high spatial frequency sensitivity develops very rapidly during infancy and that it is more mature than low spatial frequency sensitivity by 4 years of age. Contrast sensitivity development from age 4 to adulthood is characterized by expansion of sensitivity at low spatial frequencies (Gwiazda, Bauer, Thorn & Held, 1997; Richman & Lyons, 1994; Adams & Courage, 2002). Likewise, the results of the present study for 24- and 36- month-olds clearly demonstrate this developmental trend (see Figure 16). Additionally, none of the children who successfully completed the CS card procedure demonstrated impairments in CS functioning at lower spatial frequencies. Thus, redeveloping the CS cards/booklet to include fewer stimuli at lower spatial frequencies (i.e., 0.75 c/deg, 1.5 c/deg) may make the test more suitable for screening very young children. Nonetheless, the present study

provides preliminary data on using contrast sensitivity measures within a screening setting. The results of the present study coupled with the clinical advantages of the CS technique clearly warrant further research into developing a more easily administered, time-efficient method for assessing CS during infancy and early childhood.

Autorefraction

The hand-held Welch-Allyn SureSight autorefractor represents another new technology for young pediatric populations and was used to assess refractive status in all children in the present study. This technique was extremely successful, with at least one measure of refractive error obtained from each eye in 94% of the sample. The measure was typically completed within 1 to 2 minutes, and the automated guiding system made it very easy to administer. From a screening perspective, the success of the autorefractor within this study is very encouraging as refractive error is considered one of the best predictors of amblyopia (Taylor, 1987). Traditional techniques for assessing refractive error, such as cycloplegic retinoscopy, are very time consuming, require much training and experience and, are often distressing to the child. The results of this and recent work confirm that the handheld autorefractor is a valid, reliable, and time efficient method for assessing refractive error in infancy and early childhood (Adams et al., 2002; Rowatt, Donohue, Crosby, Hudson, Simon & Emmons, 2007).

In the present study, significant refractive error was the most common visual deficit identified, with 23 children (13%) showing significantly high levels for their respective age group. The results of statistical analysis revealed that the number of significant refractive errors identified did vary significantly with age. 12-, 24-, and 36-

month olds demonstrated comparable percentages of 9%, 12%, and 7% respectively, but 32% of 6-month-olds showed significant refractive errors. Moreover, this result was true for all types of refractive error (i.e., astigmatism, hyperopia, and anisometropia). The prevalence of significant refractive errors for 12- to 36-month-olds, identified here (7-12%), concurs with established prevalence rates (6-8%) for children between the ages of 2 and 5 years (Drover et al., 2008; Junghans & Crewther, 2003; Cowen & Bobier, 2003; Donnelly et al., 2005; Mayer et al., 2001; Preslan & Novak, 1998).

The high rate of significant refractive errors, most notably hyperopia, identified in 6-month-olds is somewhat alarming but is likely explained by several factors. First, only 28 6-month-olds were assessed, and a much larger sample size is required in order to accurately estimate prevalence rates. Furthermore, referral criteria for the older two age groups were based on established norms that have been used in large scale screening programs. In contrast, the criteria used for 6- and 12-month-olds were based on the few studies that have used the SureSight autorefractor with infants (Adams et al., 2002), in combination with the referral criteria derived from large scale infant vision screening program that have used different technologies, namely photorefraction and videorefraction (Atkinson & Braddick, 1983; Atkinson et al., 1996; Anker et al., 2003). The few screening programs that have attempted to provide prevalence estimates of refractive error during the first year of life have reported prevalence rates of 5-6% for hyperopia in infants between the ages of 6-11 months (Atkinson & Braddick, 1983; Atkinson et al., 1996). The criterion for hyperopia in the present study ($>3.5D$) was the same as that used in these older large-scale infant screening programs which employed

photo and videorefraction. Although this was the accepted cutoff to define hyperopia, more recent research suggests a more lenient cutoff of +4.0D (Anker et al., 2002; Atkinson et al., 2007). In the present study, this more lenient criterion would have reduced the number of referred cases of hyperopia from 5(18%) to 2 (7%) for 6-month-olds. This cutoff may be more appropriate for screening studies in order to ensure fewer false-positives and to enhance the effectiveness of the screening program. Finally, infants are known to be hyperopic during the first few months of life and then emmetropize as hyperopia reduces substantially between 9 months to 4 year (Atkinson & Braddick, 1983). The results of the present study demonstrate clearly this developmental trend, as mean refractive error reduces from 1.35D (SD = 0.75D) at 6-months to 0.72D (SD = 0.72D) at 36-months. Nonetheless, the early identification of significant refractive errors is warranted as recent research suggests that early refractive status is predicative of later visual functioning. Notably, several infant screening studies have concluded that 8-to-9-month-old infants identified with significant hyperopia were more likely to become strabismic and demonstrate reduced acuity at 4 years of age (Atkinson et al., 1983; Atkinson et al., 1996; Atkinson & Braddick, 1983). However, it is important to note that this refers to significant and *persistent* hyperopia. It is possible that significant hyperopia identified at 6 months will decrease throughout early childhood. For example, in the Cambridge Screening Program, infant hyperopes (without spectacle correction) with a mean of +4.3D at 9-months decreased to +3.1D at 36-months (Atkinson et al., 2007). Despite the discrepancies regarding the usefulness and predictability of early refractive error measurements, the results of the present study demonstrate a feasible and time

efficient method for estimating refractive error throughout the life span. Nonetheless, there remains an obvious need to create more appropriate norms for this age group and thus more accurate referral criteria.

In contrast to hyperopia, the prevalence of other identified refractive errors among the study sample concur well with established norms. Myopia has been estimated to have a prevalence rate of approximately 0.25% among infants (Atkinson et al., 1996; Anker et al., 2003; Atkinson et al., 2007) and 1.1% (Drover et al., 2008) among preschool aged children. Likely attributable to the relatively smaller sample size used here, no cases of significant myopia were identified in the present study. Using a criterion of 1.5 D difference between the eyes, the prevalence rate for anisometropia for 6- to 9- month-olds is estimated to be approximately 1.5% (Atkinson et al., 1983; Atkinson et al., 1996). In the present study only two 6-month-olds (7%) and one 12-month-old (3%) were identified with anisometropia. It is likely that the 1.75 D cutoff used here is appropriate. Very few studies have provided criteria for identifying astigmatism in infants and the value used in the present study was based on an average of normative values found previously in this age group. Although previous research has documented significant astigmatism in a large proportion of infants, the developmental pattern for this age group is still very uncertain. However, the clinical criteria used to identify astigmatism among 6- and 12-months appears appropriate (2.75D) as only two 6-month-olds (7%) and two 12-month-olds (6%) were identified with possible astigmatism.

Ocular Alignment

Like autorefraction, tests of ocular alignment were very successful with all age groups. Strabismus is a common cause of amblyopia, thus, tests of alignment represent an important part of any screening program for amblyogenic factors. 94% of all children completed the Hirschberg corneal reflex test of ocular alignment. This test was extremely easy to administer and was completed within 1 to 2 minutes for all age groups. The results of this and other studies confirm the Hirschberg corneal reflex as a simple method for assessing alignment in early infancy. Prevalence rates for disorders of alignment and motility within Canada have been estimated to be between 1.2% and 4.5% (Donnelly et al., 2005; Williams et al., 2001). The rate of abnormalities was lower in the present study with an estimated prevalence among children of 0.5%. However, it is important to note that although recommended by North American vision and pediatric associations, the Hirschberg corneal reflex is the most rudimentary method for assessing ocular alignment/motility. For older children the gold standard test of ocular alignment is the cover test.

Notably, all identified cases of ocular misalignment among the infant age groups were cases of esotropia, in which one eye is turned in. Alignment of the visual axis typically occurs during the first three months of life, with smooth, synchronized eye movements developing by 6-months. The success of this test with all age groups and the pattern of development of eye alignment and motility highlights the importance of this technique within screening programs for infants and very young children, with the

additional recommendation that the cover test be administered to children beyond 2-years.

Stereoacuity

Stereopsis is recommended for vision screening programs in order to assess binocular functioning, as poor stereoacuity is often present in individuals who have experienced some form of monocular occlusion or monocular dysfunction (Hall & Elliman, 2002). The Randot Preschool Stereoacuity Test and/or the Random Dot E Stereo Test were attempted in all 24- and 36-month-olds children. Tests of stereoacuity in 36-month-olds were very successful, with 79% completing the test. In contrast, only 23% of 24-month-olds completed this procedure, as the test was simply too complex for this age group. Binocular vision is an extremely important aspect for screening possible amblyopia, and tests of stereopsis will likely remain an integral part of screening programs for children 36-months and older. However, the results of the present study suggest that tests of stereoacuity attempted here are not recommended for 24-month-olds, at least within a screening setting. Alternative tests of stereoacuity are currently available that may be more appropriate for younger age groups. These include the Randot Stereo Smile Test and the Randot Stereo Smile Test II. Both are preferential looking based methods and thus less complex and more suitable for children from 6-months to 5 years. Given that stereopsis develops by 3-months and is established as early as 6-months, time-efficient and easy to administer tests of stereoacuity would still be a valuable component for future infant and early childhood vision screening programs.

Three cases of reduced stereoacuity (5%) were identified among 24- and 36-month-olds. A previous study estimated that the prevalence of stereoacuity deficits is approximately 0.2% among children between the ages of 2 and 5 years (Drover et al., 2008). The slight discrepancy in prevalence rates is likely attributable to the small sample of children who were administered tests of stereoacuity ($n = 64$). Also, the present study involved a much younger sample and difficulties with comprehension and attention likely contributed to the higher than anticipated rate of reduced stereoacuity (Drover et al., 2008). Nonetheless, the results are encouraging (i.e., prevalence rates are not high) in that the criteria used here are far more strict (> 500 arc sec on Randot E; > 400 arc sec on Randot Preschool) than have been used typically in preschool vision screening programs (600 to 1980 arc sec; American Academy of Pediatrics; American Academy of Ophthalmology; Newman & East, 1999).

Summary and Recommendations for Future Research

The present study attempted to develop and provide an analysis of a battery of vision assessment tools used within a screening setting for children 6- to 36-months of age. The results reveal that a comprehensive assessment of visual functioning in very young children can be obtained efficiently with measures that minimize the time requirement and tester expertise. Despite the obvious successes of the present study, there are several limitations that may affect the accuracy of the results and should be considered during future research. To truly validate the success of the screening program a gold standard exam of all identified cases of possible abnormalities (positive cases) should be provided to estimate the program's sensitivity and specificity. Furthermore, as

is the case with all screening studies, the objective is to obtain a thorough assessment of vision in a time efficient and cost efficient manner. Therefore, because of these constraints, a completely comprehensive assessment of vision and, in turn, highly accurate estimates of prevalence rates are not possible. Thus, the estimated rates of visual impairment presented here should be interpreted with caution.

An additional limitation of the present study is the lack of individual test times. Providing individual test times for each age group would provide an estimate of the success of each test as well as its practicality within a screening setting. Furthermore, the results of the study do not offer a suggested order of administering the tests. Factors such as monocular occluding glasses, attentional waning and fatigue are likely more of a factor with infants and toddlers compared to the age at which most children are typically screened. Additionally, some tests took substantially longer to administer. Therefore, it is likely that there is particular order of presenting the tests that may improve completion rates. Based on tester experiences in the present study, it is suggested that tests involving monocular occluding glasses be separated within the sequence of the test battery to minimize distress, particularly with 6- and 12-month-olds. Also, separating tests that take substantially longer to administer (i.e. TAC, CS cards) may reduce the effects of attentional waning and fatigue.

There were obvious difficulties administering the entire test battery to 6- and 12-month-olds. However, it is important to note that because 24- and 36-month-olds were screened within their daycare centers it was often possible for testing to take place over 2 sessions, if necessary. This may be an option for future testing of 6- and 12-month-olds.

Test sessions often ended before completion of the battery. Due to fatigue or distress of the infant, administering the test battery over two shorter sessions may increase completion rates for all tests. Also, with two testing sessions, it may be possible to include tests that were considered too time consuming or attentionally demanding to include within a single session (i.e. CS cards, Randot Stereo Smile test).

Conclusion

Research has shown that early vision screening for amblyopia and its risk factors results in better outcomes and reduced prevalence of amblyopia, the most common and most highly preventable eye disease among children and adults. Although early vision screening is promoted, little is known about the most favorable screening strategy and the optimal age to initiate screening. The present study was successful in demonstrating that a combination of methods are capable of providing a reasonably comprehensive analysis of visual functioning of children between the ages of 6- and 36-months. In previous work, a number of the tests used in the present study were assessed individually, but few studies combined these tests with others to form a larger clinically oriented screening battery for toddlers. Moreover, no other study to our knowledge has implemented such a comprehensive collection of methods for infants. As a result, the present study represents the first attempt to assess the usability of new tests and technologies, along with traditional methods, to screen vision in infants and young children.

In most developed countries, children are typically screened around the age of 3 or 4, an age at which the majority of cases of amblyopia have developed and may have

been present for years. The evidence for early sensitive, or critical periods, suggests that the best opportunity for prevention and treatment can be expected if the screening takes place as early in life as feasible. Early infancy to 3 years marks a critical period of plasticity during which synaptic connections within the brain are capable of rearranging based on experience. Within the visual system, healthy development depends on clear and balanced input from each eye. This critical period extends for a variable period of time, but the extent of the plasticity diminishes with age, thus, responsiveness to treatment lessens with age and the depth of impairment is influenced by the duration of the visual abnormality. The ability to screen children at such a young age, during the critical period of development, has been made possible by the advancements in technology capable of detecting amblyogenic factors, such as significant refractive error, poor visual acuity and strabismus. The promising results of the present study highlight the potential to screen children at a much younger age than is currently standard. The success of such a comprehensive screening battery with very young children could potentially have profound effects on the overall reduction of amblyopia within the population and represents an important first step in the assessment and further development of childhood screening programs. Nonetheless, the results of the present study highlight the need for further research. There remains an overall lack of data regarding paediatric eye disease in Canada and most other developed countries. In order for infant screening to reach its full potential, more research is necessary to gain a better understanding into the development and predictability of amblyogenic risk factors identified during screening. The present study has successfully identified a collection of

tests that appear reliable, are easily administered and are time efficient for assessing visual functioning in very young children. Using these and similar methods, researchers can focus on the continuous assessment of both visually normal and abnormal children identified during infancy. This will allow for further evaluation of the visual system during the critical period of development, and from there, insight into the progression of identified amblyogenic factors and their predictive value for later visual functioning.

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Appendix A

St. John's Regional Preschool Vision Screening Program

Study Information and Request to Participate

Dear parents,

We are a team of researchers at Memorial University who are currently initiating a vision screening study at all daycare centers in the St. John's area. The purpose of the study is to detect children with early, subtle visual disorders such as a turned eye, poorly developing visual acuity or focusing problems. At the same time, we wish to evaluate the effectiveness of the tests used in the screening process. There is a critical need for screening research, because if undetected and untreated, early disorders may lead to permanent visual deficits which in later years, are very difficult to correct surgically or with medication or therapy. Thus, it is important to detect and treat any existing visual disorders well before the school years in order to allow the child to perform to the best of his/her abilities both academically and socially. Furthermore, our research team here in Newfoundland is at the forefront as there are currently no effective screening programs within any Canadian province. We hope that the results of this study will provide the basis for effective early vision screening in Newfoundland and across the country.

In this study, each child's vision will be assessed with a battery of tests that are not typically used until the elementary school years and also go well beyond the typical public health pre-kindergarten vision check. The tests include: (1) the Landolt C visual acuity test, (2) the cover-uncover test, (3) the Randot stereo test, (4) the contrast sensitivity cards, and (5) autorefraction. All of these tests are simple, non-threatening and most children enjoying doing them as they are designed for preschoolers. Specific details of each test are provided at the end of this letter.

The entire screening procedure will be conducted at your child's daycare center and should be completed in approximately 20 minutes. The tests will be performed by very experienced examiners who have tested thousands of infants and children in the past. Although most children usually find the testing enjoyable, we will be careful not to proceed if the child gives any indication that s/he is uncomfortable, or becomes uninterested.

We expect that most children will show normal levels of vision. However if a child scores below the norms for other children of the same age, he/she will be retested at a later date, likely within 2 weeks. If after the second test, his/her scores are still below the norm, you will be offered the opportunity to bring him/her to the optometrist or ophthalmologist who is part of our team, to receive a follow-up eye exam. Each child's results are confidential, will be safeguarded, and will not be released without parental permission. Note however, that your child's results can be made available to you any time upon your request. You also have the right to withdraw from the study at any point (even *after* your child has been tested) and all of the results from your child will be discarded.

In our opinion, there are no apparent harms to participation and the benefits may be substantial, especially if we determine that your child has a vision problem and may benefit from treatment. Finally, participation in this study (or not) will in no way affect your child's regular medical evaluations, including the preschool vision check which is usually conducted by a Public Health Nurse prior to Kindergarten.

DETAILS OF THE TESTS TO BE ADMINISTERED:

(1) **The Landolt C test** is a chart (like the adult BIG E chart) containing rows of Cs of different sizes. The child must locate the position of the Cs opening or gap. Children who cannot complete the Landolt C test (usually 2- and 3-year-olds) will be assessed with the Lea Symbols test which is a chart (or plastic booklet) with symbols (houses, hearts, squares, and circles) of different sizes. The smallest Landolt C or Lea Symbol that the child can see gives us an indication of his/her visual acuity, traditionally the most important clinical aspect of one's vision.

Children who can not complete either of these tests will be assessed with the Teller Acuity Cards. These are a set of rectangular cards that contain black and white stripes of different sizes. Children are shown cards containing stripes of progressively smaller size and asked to point to them. The smallest size of the stripes detected provides an estimate of visual acuity.

(2) The **cover-uncover test** is used to detect strabismus (an eye turn). During this test, the child looks at a stuffed toy while one eye is covered very briefly with a small plastic paddle. The eyes are observed after the cover is removed to see if they move and function normally. The test is then quickly repeated with the other eye covered. Children will also be assessed with the Hirschberg corneal reflex in which a penlight is briefly shone into his/her eyes. If the reflection of the light is asymmetrical, the child may possess an eye turn. Also, each child's eye movements will be examined as he/she will be asked to follow the penlight as it is moved in several directions (with the light off).

(3) The **Randot E Stereotest** measures depth perception. The test consists of two cards: one contains an "E" that can be seen only with special polarized "stereo" glasses that the child wears, whereas the other plate is a blank. A child with normal stereo (3-D) vision will be able to correctly identify the "E". Children who are too young to complete this test will be tested with the simpler Randot Stereosmile Cards which consists of a series of large rectangular cards, each containing a 3-D smiling face.

(4) The **contrast sensitivity card procedure** consists of a series of rectangular cards and is similar to the Teller Acuity Cards. Each card contains black and white stripes of a specific size and contrast. Children will be instructed to point at the stripes if they can see them.

(5) Finally, each child will be assessed with the Welch-Allyn SureSight autorefractor, a hand-held camera-like device that uses a light to obtain a rapid measurement of the eye's optics (the eye's ability to focus an image). This instrument measures the degree of myopia (nearsightedness), hyperopia (farsightedness), or astigmatism in each eye.

This study has been approved by the Interdisciplinary Committee on Ethics in Human Research (ICEHR) at MUN. The results of this study will likely be published in well-established medical, neuroscience and psychology journals. If you wish to have your child participate, please complete the portion of the form below as soon as possible and return it to your child's daycare teacher. If you have additional questions or concerns, please contact the study supervisor, Dr. Russell J. Adams (737-8496), James Drover (737-4786) or the secretary of the ICEHR at 737-8368. Please keep this sheet as a reference. There is also a copy of this letter on file at your child's daycare Centre if you happen to misplace this information. Thank-you.

Very sincerely,

Russell J. Adams, PhD.
Department of Psychology
Department of Pediatrics

Mary L. Courage, PhD.
Department of Psychology
Department of Pediatrics

James R. Drover,
Ph.D. Candidate
Department of Psychology

Please return this portion as soon as possible to your child's daycare Centre or teacher. We hope to begin testing in the upcoming week.

I have read and understand all of the information pertaining to the **St. John's Regional Preschool Vision Screening Program** and wish to have my child participate.

Child's Name _____

Child's Daycare _____

Child's Birth Date _____

Days and sessions (AM/PM) that your child attends daycare

Parent's Name _____

Parent's Signature _____

Today's Date _____

(Optional) : Your phone # _____ and/or email

Have we tested your child before?? _____ If yes, when
(approximately) _____ and where _____.

Is there anything that you would like to communicate to the researchers about your child or any question that you may have?



